



ECC Report **366**

Feasibility of a potential shared use of the 6425-7125 MHz frequency band between Mobile/Fixed Communications Networks (MFCN) and Wireless Access Systems including Radio Local Area Networks (WAS/RLAN)

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0 EXECUTIVE SUMMARY

This Report studies the feasibility of the potential shared use of the Upper 6 GHz band (6425-7125 MHz) by Mobile/fixed communications networks (MFCN) and Wireless Access Systems including Radio Local Area Networks (WAS/RLAN). The Report assesses the technical impact and potential benefits and drawbacks associated with potential different sharing approaches .

Section 1 provides some introduction, while section 2 provides the parameters used in the studies (some studies used different parameters which are described in their associated summaries in section 4).

Different sharing approaches and new sharing mechanisms including cross-technology sensing to help improve detection of MFCN by WAS/RLAN and vice versa are discussed in section 3, and some of which have been assessed by relevant studies in this Report.

Various studies in this Report, summarised in section 4, consider the impact on performance from a network and user perspective of MFCN macro-cell coverage and capacity as well as spectrum access/throughput for WAS/RLAN due to shared use of the Upper 6 GHz band with different sharing scenarios and approaches.

All relevant studies assume that WAS/RLAN would either cease transmission or take some other mitigating measure when MFCN are detected above a given threshold. MFCN detection has been assumed to be perfect in all relevant studies. Practical implementations and uncertainties in detection, decoding or subsequent actions have not been considered, including identifying relevant requirements to be addressed in harmonised standards by ETSI.

Section 5 discusses some MFCN deployment considerations and provides results of some Upper 6 GHz trials undertaken.

The main conclusions of this Report are detailed in section 6, including the evaluation of potential sharing mechanisms. Issues for further consideration are also highlighted.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
2D-DFT	Two-dimensional discrete Fourier transform
3GPP	3 rd Generation Partnership Project
5G	5 th generation of mobile networks
5G NR	5G New Radio
6G	6 th generation of mobile networks
AAS	Active Antenna System
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
AFC	Automatic Frequency Coordination
AR	Augmented Reality
AP	Access Point
ATSSS	Access Traffic Steering, Switching, and Splitting
AWGN	Additive White Gaussian Noise
BBF	Broadband Forum
BEL	Building Entry Loss
BFWA	Broadband Fixed Wireless Access
BS	Base Station
CBRS	Citizens Broadband Radio Service
CDF	Cumulative Distribution Function
CEPT	European Conference of Postal and Telecommunications Administrations
CPE	Customer Premises Equipment
CW	Continuous Wave
DDoS	Distributed Denial of Service
DFS	Dynamic Frequency Selection
DFT-S-OFDM	Discrete Fourier Transform-Spread-Orthogonal Frequency Division Multiplexing
DL	Downlink
EC	European Commission
ECC	Electronic Communications Committee
ED	Energy Detection
EDT	Energy Detection Threshold
<i>e.i.r.p.</i>	Equivalent Isotropically Radiated Power
ETSI	European Telecommunication Standards Institute
EU	European Union
FDD	Frequency Division Duplex

Abbreviation	Explanation
FILS	Fast Initial Link Setup
FS	Fixed Service
FSS	Fixed Satellite Service
FTP	File Transfer Protocol
FWA	Fixed Wireless Access
HARQ	Hybrid Automatic Repeat request
HLP	Higher Layer Payload
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
I/N	Interference to Noise Ratio
ISD	Inter-site distance
ISPs	Internet Service Providers
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
JRC	Joint Research Centre of the European Commission
Lower 6 GHz	Lower 6 GHz band: 5925-6425 MHz
LBT	Listen-Before-Talk
LOS	Line-of-Sight
LPI	Low Power Indoor
MAC	Media Access Control
MFCN	Mobile/Fixed Communications Networks
MIMO	Multiple-Input and Multiple-Output
MMSE-IRC	Minimum Mean-Square Error Interference Rejection Combining
MNO	Mobile Network Operator
N3IWF	Non-3GPP Interworking Function
NLOS	Non-Line-of-Sight
NR	New Radio
OBUE	Operating Band Unwanted Emissions
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out of Band
OOK	On-Off Keying
OTA	Over-The-Air
PMSE	Programme Making & Special Events
PHY	Physical Layer
PSC	Preferred Scanning Channel
RAS	Radio Astronomy Service
RB	Resource Block
RAT	Radio Access Technology

Abbreviation	Explanation
RF	Radiofrequency
RLAN	Radio Local Area Networks
RSPG	Radio Spectrum Policy Group
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RX	Receiver
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
SCS	Subcarrier Spacing
SE	Spectral Efficiency
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SSB	Synchronisation Signal Block
STA	Station mode
TPC	Transmission Power Control
TDD	Time Division Duplex
TNGF	Trusted Non-3GPP Gateway Function
TR	Technical Report
TRX	Transceiver
TX	Transmitters
TVWS	TV White Spaces
Upper 6 GHz	Upper 6 GHz band: 6425-7125 MHz
UE	User Equipment
UL	Uplink
ULL	Ultra Low Latency
UMa	Urban Macro
VLP	Very Low Power
VR	Virtual Reality
WAS/RLAN	Wireless Access Systems / Radio Local Area Networks
WLAN	Wireless Local Area Network
Wi-Fi	IEEE 802.11x standards for wireless networking
WRC	World Radiocommunication Conference
XTS	Cross-Technology Signalling

1 INTRODUCTION

This Report studies the feasibility of the potential shared use of the Upper 6 GHz band (6425-7125 MHz) by MFCN (Mobile/fixed communications networks) and Wireless Access Systems including Radio Local Area Networks (WAS/RLANs). The Report assesses the technical impact and potential benefits and drawbacks associated with potential sharing mechanisms outlined in section 3.5.

The Upper 6 GHz band is currently subject to competing industry demands. There are differing views on how the Upper 6 GHz band should be used within the existing allocation to the mobile service. However, the RSPG Opinion on WRC-23 [18] stated that *“RSPG recommends that the Commission should clarify explicitly the intention for EU to consider, by 2024 or later, the best usage of the frequency band 6 425-7 125 MHz for wireless broadband in the future: either IMT, or WAS/RLAN or a shared framework between IMT and WAS/RLAN, possibly depending on the portion of this frequency band, noting that an IMT identification does not exclude other use of the band, for example a shared future use between IMT and WAS/RLAN or WAS/RLAN alone”*.

Also, WRC-23 has agreed an IMT identification of the 6425-7125 MHz frequency range in Region 1 and of the 7025-7125 MHz frequency range in Region 3 (RR No. **5.457E**). The 6425-7125 MHz frequency range is also identified for IMT in two countries in Region 2 (RR No. **5.457F**) and the frequency range 6425-7025 MHz in three countries in Region 3 (RR No. **5.457D**). For the whole frequency range it is indicated that the frequency bands are also used for the implementation of wireless access systems (WAS), including radio local area networks (RLANs).

In the context of this Report, shared use means the use of the Upper 6 GHz band by MFCN (with a range of parameters, including macro-cellular base stations) and WAS/RLAN, at the same time and/or in the same geographical area and/or in the same frequency. ITU considers that any method used to facilitate shared use of spectrum has to take into account the four dimensions: frequency, time, spatial location and signal separation¹.

Different sharing approaches and sharing mechanisms are analysed in this Report, including:

- Sharing results for MFCN with full power² and WAS/RLAN (Low Power Indoor (LPI) and Very Low Power (VLP)) with Energy Detection Threshold (EDT) only;
- Enhanced detection techniques;
- MFCN outdoor coverage, WAS/RLAN indoor coverage through reduced MFCN BS e.i.r.p.;
- MFCN downlink/uplink issues and information from field trials;
- Issues for further consideration including band split approaches.

This Report does not include studies on coexistence with other services and applications within the Upper 6 GHz band such as Fixed Service (FS), Radio Astronomy Service (RAS), Programme Making Special Event (PMSE) and Fixed-Satellite Service (FSS). Although not considered within this Report and subject to further studies, some of the proposed sharing mechanisms may have the potential to also support the protection of incumbent users where applicable, noting that this could mean that MFCN and/or WAS/RLAN deployment may not be possible at certain locations. In addition, it is noted that EU Member States shall not adopt technical and operational conditions applicable to any new application that unduly restrict the continued use of WAS/RLAN in the 5945-6425 MHz frequency band (see Commission Implementing Decision (EU) 2021/1067 [19]).

This Report is used by CEPT, as appropriate, when developing its response to Task 2 (potential shared use between Wireless Broadband Electronic Communication Systems and WAS/RLAN) of the EC Mandate [41].

¹ Recommendation ITU-R SM.1132, [14], *“Interservice sharing exists when two or more radiocommunication services effectively use the same frequency band. Article 1 of the Radio Regulations (RR) (Nos. 160-168) defines the parameters to be taken into account in frequency sharing. Utilization of the radio spectrum is dependent on frequency, time, spatial location, and orthogonal signal separation. Any sharing of the spectrum will have to take into account one or more of these four dimensions. Sharing can be accomplished in a straightforward fashion when any two of these dimensions are in common and the third and/or fourth dimension differs by a degree sufficient to ensure that all the involved services (two or more) can operate satisfactorily. Sharing can also be accomplished when services have all four dimensions in common. In such cases, sharing is accomplished by applying technical conditions which do not compromise the performance requirements of the services involved.”*

² Values of MFCN base station e.i.r.p. cited in this Report refer to the e.i.r.p. in the main beam direction. In the context of this Report, “full power” MFCN base stations means MFCN base stations radiating at high e.i.r.p.

2 PARAMETERS FOR STUDIES

2.1 MFCN PARAMETERS

2.1.1 Parameters aligned with characteristics used in the WRC-23 studies

The following equations approximate the spectral efficiency (SE) over a channel with a given SINR (dB), when using link adaptation:

$$\text{Spectral Efficiency (SINR), bps/Hz} = \begin{cases} 0 & \text{for SINR} < \text{SINR}_{\text{MIN}} \\ \alpha \cdot S(\text{SINR}) & \text{for SINR}_{\text{MIN}} \leq \text{SINR} < \text{SINR}_{\text{MAX}} \\ \alpha \cdot S(\text{SINR}_{\text{MAX}}) & \text{for SINR} \geq \text{SINR}_{\text{MAX}} \end{cases}$$

where:

- $S(\text{SINR})$ is Shannon bound, $S(\text{SINR}) = \log_2(1 + 10^{(\text{SINR}/10)})$, bps/Hz;
- α is attenuation factor, representing implementation losses;
- SINR_{MIN} is minimum SINR of the code set, dB;
- SINR_{MAX} is maximum SINR of the code set, dB.

The parameters α , SINR_{MIN} and SINR_{MAX} can be chosen to represent different modem implementations and link conditions. The parameters in Table 1 represent a baseline case for 5G NR, which assumes:

- 1:1 antenna configurations;
- Additive white Gaussian Noise (AWGN) channel model;
- Link Adaptation (see Table 1 for details of the highest and lowest rate codes);
- No Hybrid Automatic Repeat request (HARQ).

Table 1: Parameters describing baseline link level performance for 5G NR [20]

Parameter	DL	UL	Notes
α	0.6	0.4	Represents implementation losses
SINR_{MIN} , dB	-10	-10	Based on QPSK, 1/8 rate (DL) & 1/5 rate (UL)
SINR_{MAX} , dB	30	22	Based on 256-QAM, 0.93 rate (DL) & 64-QAM, 0.93 rate (UL)

2.1.2 System parameters

The following tables provide the MFCN parameters for the Upper 6 GHz band (6425-7125 MHz).

System parameters are taken from [20].

Table 2: 5G NR base station and user equipment characteristics in 6425-7125 MHz

No.	Parameter	Base station (AAS)	User equipment
1	Duplex Method	TDD	TDD
2	Channel bandwidth (MHz)	100 MHz (typical)	100 MHz (typical)
3	Signal bandwidth (MHz)	To be specified. Will be derived from channel bandwidth, see [1] § 5.3.2.	To be specified. Will be derived from channel bandwidth, see [2], § 5.3.2.
4	Transmitter characteristics		

No.	Parameter	Base station (AAS)	User equipment
4.1	Power dynamic range (dB)	0 dB	56 dB
4.2	Spectral mask (dB)	Category B: (Note 1) See Table 3 (Wide Area BS) ($\Delta f_{OBUE} = 100$ MHz)	See Table 4
4.3	ACLR (dB)	38 dB	26 dB
4.4	Spurious emissions	Category B: (Note 1) See [1], § 6.6.5	See [2], § 6.5.3.
4.5	Maximum/typical output power (dBm)	Defined by the conducted power per antenna element, see entry 1.9 in Table 7 for typical values.	23 dBm
5	Receiver characteristics		
5.1	Noise figure (dB)	6 dB (Wide Area BS) 11 dB (Medium Range BS) 14 dB (Local Area BS)	9-13 dB
5.2	Sensitivity (dBm)	To be specified	To be specified
5.3	Blocking response	In-band blocking level: -43 dBm (Wide Area BS) -38 dBm (Medium Range BS) -35 dBm (Local Area BS) Interferer type: 20 MHz DFT-S-OFDM NR signal, 15 kHz SCS, 100 RB. Out-of-band blocking level: -15 dBm, Interferer type: CW $\Delta f_{OOB} = 100$ MHz (Note 2)	See [2], §7.6, Tables 7.6.2-4 and 7.6.3-4
5.4	ACS	42 dB	32 dB
5.5	SINR operating range (dB)	See "SINR operating range and mapping function"	
<p>Note 1: Base station operating band unwanted emissions define all unwanted emissions in the supported downlink operating band plus the frequency ranges extending Δf_{OBUE} above and Δf_{OBUE} below each band. Base station unwanted emissions outside of this frequency range are limited by the spurious emissions requirement.</p> <p>Note 2: Base station in-band blocking applies in the supported uplink operating band plus the frequency ranges extending Δf_{OOB} above and Δf_{OOB} below each band, excluding the downlink frequency range in case of an FDD operating band. Out-of-band blocking applies from 1 MHz to 12.75 GHz, excluding the in-band blocking frequency range, but including the downlink frequency range in case of an FDD operating band. Requirements are defined assuming a receiver desensitization of 6 dB.</p> <p>References used in the Table (The excerpts of these references are available in the Annexes of Annex 4.4 to Working Party 5D Chairman's Report Document 5D/716-E (June 2021) [20]):</p> <p>(1) 3GPP TS 38.104 v.16.6.0 (2020-12), "NR; Base Station (BS) radio transmission and reception". [1] (2) 3GPP TS 38.101-1 v.16.6.0 (2020-12), "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone"[2]</p>			

Table 3: AAS BS Spectral mask (Operating band unwanted emissions limits) for 6425-7125 MHz operation - Category B

Frequency offset of measurement filter -3 dB point from the carrier frequency, Δf	Basic limits	Measurement bandwidth
$0 \text{ MHz} \leq \Delta f < 50 \text{ MHz}$	$-7 \text{ dBm} - \frac{7}{50} \left(\frac{f_offset}{\text{MHz}} - 0.05 \right)$	100 kHz

Frequency offset of measurement filter -3 dB point from the carrier frequency, Δf	Basic limits	Measurement bandwidth
$50 \text{ MHz} \leq \Delta f < \min(100 \text{ MHz}, \Delta f_{\max})$	-14 dBm	100 kHz
$100 \text{ MHz} \leq \Delta f \leq \Delta f_{\max}$	-15 dBm	1 MHz

Note: Δf_{\max} is equal to $f_{\text{offset,max}}$ minus half of the bandwidth of the measuring filter, where $f_{\text{offset,max}}$ is the offset to the frequency $\Delta f_{\text{OBUe}} = 100 \text{ MHz}$ outside the downlink operating band.

Table 4: User equipment Spectral mask for 6425-7125 MHz operation

Δf_{OOB} (MHz)	Spectrum emission limit (dBm) / Channel bandwidth										Measurement bandwidth
	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz	
$\pm 0-1$	-10	-10	-10	-10							1% channel bandwidth
$\pm 0-1$					-21	-21	-21	-21	-21	-21	30 kHz
$\pm 1-5$	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	1 MHz
$\pm 5-105$	See [2] § 6.5.2.2, Table 6.5.2.2-1										

2.1.3 MFCN deployment related parameters

MFCN deployment related parameters are taken from [20].

Implementation of AAS (see Table 7) is considered for MFCN base stations in these frequency bands. Implementation of AAS is not considered in MFCN User Equipment.

Table 5: Deployment-related parameters for bands between 6 and 8 GHz

	Urban / suburban macro	Small cell (outdoor) / Micro-cell	Indoor (small cell)
Deployment density (Note 1)	10 BSs/km ² urban / 2.4 BSs/km ² suburban (Notes 2, 3)	1-3 per urban macro-cell <1 per suburban macro site	Depending on indoor coverage / capacity demand
Antenna height	18 m urban / 20 m suburban	6 m	3 m
Sectorisation	3 sectors	Single sector	Single sector
Frequency reuse	1	1	1
Indoor base station deployment	n.a.	n.a.	100%
Indoor base station penetration loss	n.a.	n.a.	Recommendation ITU-R P.2109 [3]
Below rooftop base station antenna	Urban: 65%	100%	n.a.

	Urban / suburban macro	Small cell (outdoor) / Micro-cell	Indoor (small cell)
deployment	Suburban: 15%		
Typical channel bandwidth	100 MHz	100 MHz	100 MHz
Network loading factor (base station load probability X%) (see section 2.1.3.2 below and Recommendation ITU-R M.2101, annex 1, section 3.4.1 and 6 [4])	20%, 50%	20%, 50%	20%, 50%
TDD / FDD	TDD	TDD	TDD
BS TDD activity factor	75%	75%	75%
<p>Note 1: These density values are for small dense areas. See section 3.3 in Working Party 5D Chairman's Report Document 5D/716-E [20] for densities in larger areas.</p> <p>Note 2: "1 BS" = 1 sector in 3-sector cell.</p> <p>Note 3: This value is calculated based on use of same existing cellular grid as 3-6 GHz. It is expected that the same BS infrastructure will typically be used for networks in both 3-6 GHz and 6-8 GHz. For sharing studies requiring a specific cell size, the following values should be used: 0.3 km for urban and 0.6 km for suburban.</p>			

Table 6: User Equipment parameters for bands between 6 and 8 GHz

	Urban / suburban macro	Small cell (outdoor) / micro-cell	Indoor (small cell)
Indoor user terminal usage	70%	70%	100%
Indoor user terminal penetration loss	Recommendation ITU-R P.2109	Recommendation ITU-R P.2109	Recommendation ITU-R P.2109
User equipment density for terminals that are transmitting simultaneously (Note 1)	3 UEs per sector	3 UEs per sector	3 UEs per sector
UE height (Note 2)	1.5 m	1.5 m	1.5 m
Average user terminal output power	Use transmit power control	Use transmit power control	Use transmit power control
Typical antenna gain for user terminals	-4 dBi	-4 dBi	-4 dBi
Body loss	4 dB	4 dB	4 dB
UE TDD activity factor	25%	25%	25%
Power control model	Refer to Recommendation ITU-R M.2101, annex 1, section 4.1		
Maximum user terminal output power, PCMAX	23 dBm	23 dBm	23 dBm
Power (dBm) target value per RB, P0_PUSCH (Note 3)	-92.2	-87.2	-87.2
Path loss compensation factor, (same as "balancing factor" mentioned in Recommendation ITU-R M.2101)	0.8	0.8	0.8
<p>Note 1: UEs share equally the channel bandwidth, i.e. each UE is allocated 1/3 of the channel bandwidth (see Recommendation ITU-R M.2101, section 3.4.1, item 1e-f.). In sharing studies, it is assumed that the AAS BS beamforms towards each UE using the entire array.</p>			

	Urban / suburban macro	Small cell (outdoor) / micro-cell	Indoor (small cell)
<p>Note 2: In principle, indoor UEs are distributed over different floors of the building. It should be noted that the number of floors of buildings vary within the environment and among the countries. Moreover, the number of floors of buildings is not related to Macro BS antenna height (parameter given in Table 5). In particular in small cities, sub-urban and rural areas, many or most of antennas are installed on masts. Therefore, for outdoor BSs, indoor UEs are assumed to be modelled on the ground floor for the sharing study.</p> <p>Note 3: The target power is defined per Resource Block (RB), considering 180 kHz RB bandwidth corresponding to 15 kHz subcarrier spacing.</p>			

2.1.3.1 Antenna characteristics for 5G NR AAS base stations

Antenna characteristics for 5G NR AAS base stations are given in Table 7. Those parameters are interdependent and derived as a package, based on deployment scenarios and other requirements. Note that in September 2024, the ECC requested updates from CEPT administrations on maximum Base Station transmit power in operation in the 3400-3800 MHz frequency band. The responses from some European countries confirmed that the maximum base station *e.i.r.p.* of 78 to 82 dBm/100 MHz is representative of base stations in CEPT countries [21], which is higher than the values that can be derived from the parameters listed for Upper 6 GHz in Table 7.

Table 7: Beamforming antenna characteristics for 5G NR in 6425-10 500 MHz [20]

		Macro suburban	Macro urban	Small cell outdoor / Micro urban	Small cell indoor / Indoor urban
1	Base station antenna characteristics				
1.1	Antenna pattern	Refer to Recommendation ITU-R M.2101, annex 1, section 5			
1.2	Element gain (dBi) (Note 1)	6.4	5.5	5.5	5.5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	90° for H 65° for V	90° for H 90° for V	90° for H 90° for V	90° for H 90° for V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V	30 for both H/V	30 for both H/V	30 for both H/V
1.5	Antenna polarisation	Linear ±45°	Linear ±45°	Linear ±45°	Linear ±45°
1.6	Antenna array configuration (Row × Column) (Note 2)	16 × 8 elements	16 × 8 elements	8 × 8 elements	4 × 4 elements
1.7	Horizontal/Vertical radiating element spacing	0.5 of wavelength for H, 0.7 of wavelength for V	0.5 of wavelength for H, 0.5 of wavelength for V	0.5 of wavelength for H, 0.5 of wavelength for V	0.5 of wavelength for H, 0.5 of wavelength for V
1.8	Array Ohmic loss (dB) (Note 1)	2	2	2	2
1.9	Conducted power (before Ohmic loss) per antenna element (dBm) (Notes 9, 11)	22 (Note 5)	22 (Note 5)	16 (Note 6)	9 (Note 7)

		Macro suburban	Macro urban	Small cell outdoor / Micro urban	Small cell indoor / Indoor urban
1.10	Base station maximum coverage angle in the horizontal plane (degrees)	±60	±60	±60	N/A (Note 8)
1.11	Base station vertical coverage range (degrees) (Notes 3, 4, 10, 12)	90-100	90-120	90-120	N/A (Note 8)
1.12	Mechanical downtilt (degrees) (Note 4)	6	10	10	N/A (Note 8)

Note 1: The element gain in row 1.2 includes the loss given in row 1.8. This means that this parameter in row 1.8 is not needed for the calculation of the BS composite antenna gain and *e.i.r.p.*

Note 2: 16 × 8 means there are 16 vertical and 8 horizontal radiating elements. In the sub-array case, one implementation is 2 vertical radiating elements combined in a 2 × 1 sub-array.

Note 3: The vertical coverage range is given in global coordinate system, i.e. 90° being at the horizon.

Note 4: The vertical coverage range in row 1.11 includes the mechanical downtilt given in row 1.12.

Note 5: The conducted power per element assumes 16 × 8 × 2 elements (i.e. power per H/V polarized element).

Note 6: The conducted power per element assumes 8 × 8 × 2 elements (i.e. power per H/V polarized element).

Note 7: The conducted power per element assumes 4 × 4 × 2 elements (i.e. power per H/V polarized element).

Note 8: The boresight direction is perpendicular to the ceiling.

Note 9: In sharing studies, the transmit power calculated using row 1.9 is applied to the typical bandwidth given in Table 7-1 and 8-1 respectively for the corresponding frequency bands.

Note 10: In sharing studies, the UEs that are below the coverage range can be considered to be served by the “lower” bound of the electrical beam, i.e. beam steered towards the max. coverage angle. A minimum BS-UE distance along the ground of 35 m should be used for urban/suburban and rural macro environments, 5 m for micro/outdoor small cell, and 2 m for indoor small cell/urban scenarios.

Note 11: Sharing studies can consider other levels of conducted power but the associated antenna configuration should be clearly reported.

Note 12: Antennas are expected to conform to mask as detailed in Resolution 220 (WRC-23) of the Radio Regulations [40], which may result in some beam pointing restrictions

2.1.3.2 Network loading factor

Network loading factors provided in this Report reflect average MFCN base station activity. In order to provide required and adequate quality of service, MFCN networks are designed and dimensioned to avoid undue congestion, such that overall most of the cells are not heavily loaded simultaneously and only a small percentage of cells are heavily loaded at any specific point in time. The average loading would therefore be significantly lower when averaged over a sufficient number of MFCN transmitters.

A network loading value of 20% would normally represent a typical/average value for the loading of base stations across a network (or part thereof) and should be used for sharing and compatibility studies that are considering a relatively wide area (e.g. a large city, province, country or satellite footprint). For studies involving only a small area where there are only a few MFCN transmitters, a maximum network loading value of not more than 50% may be used.

2.1.4 Protection criterion for MFCN

Table 8 contains the MFCN protection criterion (irrespective of the number of cells and independent of the number of interferers). This criterion has been developed without considering any associated probability.

Table 8: Protection criterion for MFCN [20]

Protection criterion	Value
I/N	-6 dB

2.1.5 Other proposals

Table 9: Indoor UE height distribution

Floor	Ground	1	2	3	4	5	6	7	8	9
Height	1.5	4.5	7.5	10.5	13.5	16.5	19.5	22.5	25.5	28.5
Probability (%)	24.66	20.36	14.05	11.27	9.19	7.52	5.56	3.88	2.41	1.10

Note: ECC Report 316 [5], height distribution of a large city with more than 100000 households

2.2 WAS/RLAN PARAMETERS

Table 10: WAS/RLAN Parameters

RLAN Parameter	Value
Antenna gain distributions	As defined in sections 2.2.1.1 and 2.2.2.3
WAS/RLAN antenna heights	ECC Report 316 distributions hold for site-general studies. Site-specific studies may incorporate site-specific data.
Bandwidth distribution	Updated to account for 320 MHz: 20 MHz (10%), 40 MHz (5%), 80 MHz (30%), 160 MHz (35%), 320 MHz (20%) (Assumed to be the same as in ECC Report 302 [6], ECC Report 316 [5] and ECC Report 364 [22])
Busy hour factor	50% and 62.7% as per ECC Report 302
Population of Europe projected for 2030	Updated projections using UN figures from https://population.un.org/wpp/Download/Standard/Population/ with the CEPT population of 688 447 000, and with 609 503 000 individuals being between 10 and 90 years of age (CEPT population 2030.xlsx – attachment can be found here) or JRC (GHS-POP) https://ghsl.jrc.ec.europa.eu JRC (GHS-POP) gives projected population in granular geographical manner for site-specific studies.
Assignment of population to urban, suburban and rural environments	ECC Report 302 [6] (when site-specific data is not available): <ul style="list-style-type: none"> ▪ Urban: 50%; ▪ Suburban: 27%; ▪ Rural: 23%. Site-specific studies: use of site-specific maps (e.g. from JRC data GHS-POP and GHS-SMOD https://ghsl.jrc.ec.europa.eu , CLC)
Market adoption factor	Scenario A (ECC Report 302): <ul style="list-style-type: none"> ▪ Low: 25% ▪ Mid: 32% ▪ High: 50% Parametric Scenario B: <ul style="list-style-type: none"> ▪ Low: 28%

RLAN Parameter	Value
	<ul style="list-style-type: none"> ▪ Mid: 36% ▪ High: 60%
RF activity factor	Scenario A (ECC Report 302): 1.97% Parametric Scenario B: 2.45%
LPI/VLP and indoor/outdoor distribution	As defined in ECC Report 316 [5] and in 2.2.1.2
License exempt spectrum	Scenario A (ECC Report 302): 90% Parametric Scenario B: No License exempt factor is considered
Upper 6 GHz factor	Scenario A (ECC Report 302 [6] methodology): 40.75% as per ECC Report 364 [22] Parametric Scenario B: 47.03% as per ECC Report 364

2.2.1 WAS/RLAN transmitter parameters to be used in sharing studies

2.2.1.1 WAS/RLAN TX normalised antenna gain distributions

The normalised antenna gain distributions for WAS/RLANs to be used in sharing studies are given below (these tables depict a maximum antenna gain normalised to 0 dBi):

- AP Distribution (see Table 13);
- VLP/Client Distribution without Body Loss (see Table 15);
- VLP/Client Distribution with Body Loss (see Table 17).

2.2.1.2 WAS/RLAN TX e.i.r.p. distributions

To obtain the *e.i.r.p.* distributions, Table 13, Table 15 and Table 17 should be used together with one indoor/outdoor distribution. This distribution represents the amount of time a device class is actively transmitting in a given time instant.

ECC Report 364 [22] used the following indoor/outdoor distribution for sharing studies with incumbents.

Table 11: WAS/RLAN indoor/outdoor and e.i.r.p. distributions

Device type		Total indoor	Total outdoor	e.i.r.p. distribution
LPI Clients	With Body Loss	21.10%	0.21%	200 mW + normalised antenna gain distribution from Table 17
	Without Body Loss	2.37%	0.00%	200 mW + normalised antenna gain distribution from Table 15
VLP	With Body Loss	9.00%	1.00%	25 mW + normalised antenna gain distribution from Table 17
AP (LPI)	Without Body Loss	66.32%	0.00%	200 mW + normalised antenna gain distribution from Table 13
Total		98.79%	1.21%	

Table 12: Absolute antenna gain distribution for WAS/RLAN AP receiver

G_{\min} (dBi)	G_{\max} (dBi)	Probability (%)
-24	-23	0.16
-23	-22	0.04
-22	-21	0.06
-21	-20	0.33
-20	-19	0.80
-19	-18	0.70
-18	-17	1.21
-17	-16	0.60
-16	-15	1.13
-15	-14	1.79
-14	-13	1.78
-13	-12	1.95
-12	-11	1.52
-11	-10	3.07
-10	-9	4.75
-9	-8	5.58
-8	-7	4.59
-7	-6	6.26
-6	-5	8.47
-5	-4	7.05
-4	-3	9.55
-3	-2	9.32
-2	-1	9.01
-1	0	8.71
0	1	5.66
1	2	2.75
2	3	1.41
3	4	1.23
4	5	0.22
5	6	0.07
6	7	0.16
7	8	0.03
8	9	0.03
9	10	0.01

Table 13: Normalised antenna gain distribution for WAS/RLAN AP transmitter

G_{\min} (dB)	G_{\max} (dB)	Probability (%)
-31	-30	0.10
-30	-29	0.07
-29	-28	0.21
-28	-27	0.05
-27	-26	0.11
-26	-25	0.36
-25	-24	0.74
-24	-23	0.65
-23	-22	0.92
-22	-21	0.59
-21	-20	1.25
-20	-19	1.24
-19	-18	2.32
-18	-17	1.97
-17	-16	2.63
-16	-15	3.61
-15	-14	3.61
-14	-13	4.71
-13	-12	5.98
-12	-11	7.05
-11	-10	6.66
-10	-9	7.82
-9	-8	8.68
-8	-7	8.47
-7	-6	8.83
-6	-5	8.44
-5	-4	4.32
-4	-3	3.08
-3	-2	1.86
-2	-1	1.81
-1	0	1.86

Table 14: Absolute antenna gain distribution for WAS/RLAN VLP/Client receiver without body loss

G _{min} (dBi)	G _{max} (dBi)	Probability (%)
-25	-24	0.15
-24	-23	0.06
-23	-22	0.25
-22	-21	0.23
-21	-20	0.10
-20	-19	0.44
-19	-18	0.39
-18	-17	1.14
-17	-16	1.12
-16	-15	1.89
-15	-14	2.20
-14	-13	3.53
-13	-12	3.74
-12	-11	4.43
-11	-10	5.50
-10	-9	6.58
-9	-8	8.42
-8	-7	9.40
-7	-6	9.87
-6	-5	8.41
-5	-4	7.62
-4	-3	6.56
-3	-2	5.55
-2	-1	4.63
-1	0	3.54
0	1	2.51
1	2	1.40
2	3	0.28
3	4	0.04

Table 15: Normalised antenna gain distribution for WAS/RLAN VLP/Client transmitter without body loss

G _{min} (dB)	G _{max} (dB)	Probability (%)
-27	-26	0.17
-26	-25	0.15
-25	-24	0.23
-24	-23	0.21
-23	-22	0.34
-22	-21	0.48
-21	-20	0.64
-20	-19	1.07
-19	-18	2.06
-18	-17	2.20
-17	-16	2.08
-16	-15	2.73
-15	-14	3.91
-14	-13	4.98
-13	-12	4.84
-12	-11	5.98
-11	-10	6.27
-10	-9	9.19
-9	-8	9.04
-8	-7	9.23
-7	-6	8.70
-6	-5	7.48
-5	-4	6.47
-4	-3	5.31
-3	-2	3.27
-2	-1	2.42
-1	0	0.56

Table 16: Absolute antenna gain distribution for WAS/RLAN VLP/Client receiver with body loss

G_{\min} (dBi)	G_{\max} (dBi)	Probability (%)
-50	-49	0.001
-49	-48	0.001
-48	-47	0.001
-47	-46	0.001
-46	-45	0.001
-45	-44	0.001
-44	-43	0.001
-43	-42	0.005
-42	-41	0.005
-41	-40	0.005
-40	-39	0.005
-39	-38	0.047
-38	-37	0.062
-37	-36	0.109
-36	-35	0.151
-35	-34	0.199
-34	-33	0.196
-33	-32	0.247
-32	-31	0.360
-31	-30	0.385
-30	-29	0.495
-29	-28	0.589
-28	-27	0.863
-27	-26	0.877
-26	-25	1.551
-25	-24	1.674
-24	-23	1.862
-23	-22	2.026
-22	-21	2.265
-21	-20	2.549
-20	-19	2.569
-19	-18	3.905
-18	-17	4.853
-17	-16	4.455
-16	-15	5.800

G_{min} (dBi)	G_{max} (dBi)	Probability (%)
-15	-14	4.995
-14	-13	4.004
-13	-12	4.353
-12	-11	4.804
-11	-10	4.753
-10	-9	4.513
-9	-8	5.334
-8	-7	4.838
-7	-6	5.252
-6	-5	4.516
-5	-4	4.409
-4	-3	3.755
-3	-2	2.620
-2	-1	1.932
-1	0	1.029
0	1	0.562
1	2	0.138
2	3	0.078

Table 17: Normalised antenna gain distribution for WAS/RLAN VLP/Client transmitter with body loss

G_{min} (dB)	G_{max} (dB)	Probability (%)
-52	-51	0.001
-51	-50	0.001
-50	-49	0.001
-49	-48	0.001
-48	-47	0.001
-47	-46	0.002
-46	-45	0.005
-45	-44	0.005
-44	-43	0.005
-43	-42	0.011
-42	-41	0.064
-41	-40	0.048
-40	-39	0.154
-39	-38	0.131
-38	-37	0.235

G_{min} (dB)	G_{max} (dB)	Probability (%)
-37	-36	0.216
-36	-35	0.261
-35	-34	0.418
-34	-33	0.291
-33	-32	0.557
-32	-31	0.633
-31	-30	0.872
-30	-29	0.891
-29	-28	1.632
-28	-27	1.776
-27	-26	1.485
-26	-25	2.125
-25	-24	2.324
-24	-23	2.451
-23	-22	2.626
-22	-21	2.358
-21	-20	2.763
-20	-19	3.883
-19	-18	3.640
-18	-17	4.637
-17	-16	5.080
-16	-15	4.598
-15	-14	4.244
-14	-13	4.216
-13	-12	4.490
-12	-11	4.460
-11	-10	4.755
-10	-9	5.078
-9	-8	5.507
-8	-7	4.680
-7	-6	5.277
-6	-5	4.310
-5	-4	2.913
-4	-3	2.054
-3	-2	1.108
-2	-1	0.449

G_{min} (dB)	G_{max} (dB)	Probability (%)
-1	0	0.227
0	1	0.051

2.2.1.3 Spectrum emission mask

WAS/RLAN spectrum emission mask is defined in ETSI EN 303 687, clause 4.3.4.3 [7].

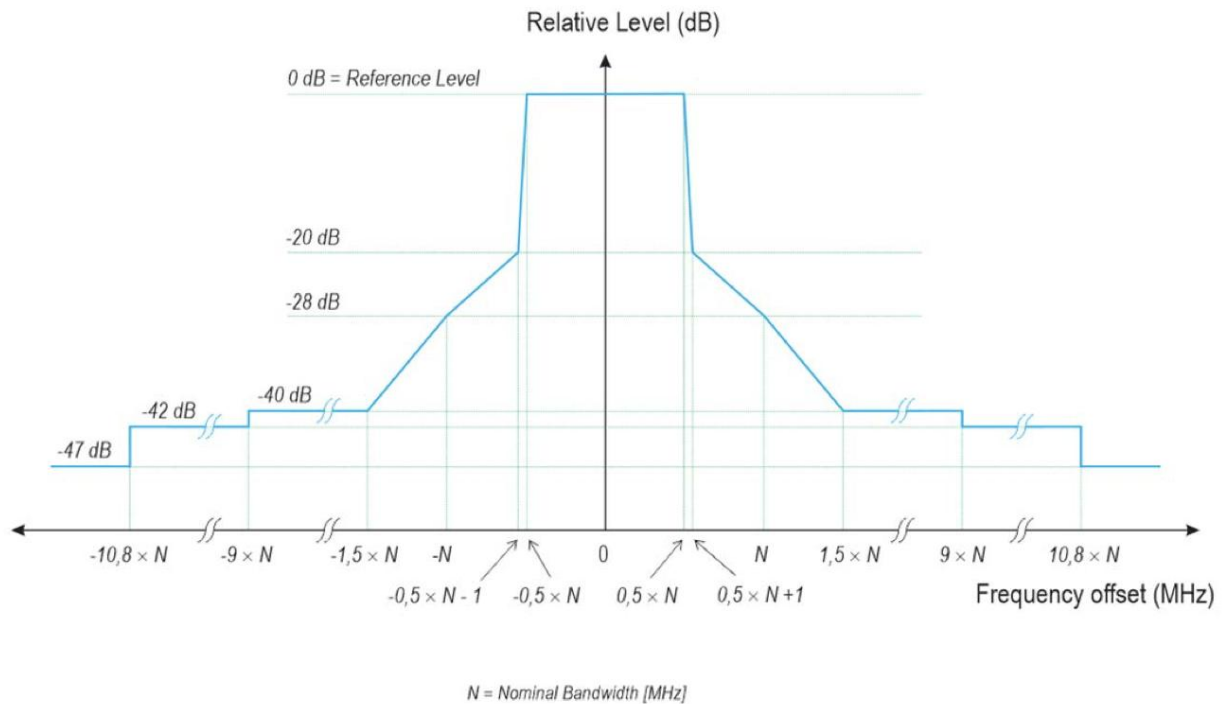


Figure 1: WAS/RLAN transmit spectral power mask

2.2.2 WAS/RLAN receiver parameters to be used in sharing studies

In addition, studies could also consider:

- using measured/tested WAS/RLAN equipment performance parameters rather than generic limits from standards/regulation, as appropriate; for example, new measurements or ECC Report 310 [23] (section 8.3.1 for WAS/RLAN in the 2.4 GHz band and in the 5 GHz band);
- the higher performance levels of receiver selectivity and blocking in ETSI EN 300 328 [24] and EN 303 687 (noting that these standards cover wideband transmission systems in the 2.4 GHz band and WAS/RLAN in the Lower 6 GHz band, respectively);
- existing levels of WAS/RLAN energy detection threshold (EDT) are shown in section 2.2.2.4, however the sharing studies may conclude on different parameters as part of improved sensing requirements.

2.2.2.1 Protection criteria

Studies may want to consider various metrics other than I/N, such as throughput loss or SINR degradation for example, noting that for the 5 GHz band a protection criterion is stated in Recommendation ITU-R M.1739 [8] (I/N = -6 dB defined without percentage of time associated to it).

2.2.2.2 Noise figure

Noise figure of 9 dB (as a baseline) and 7 dB [25] (for sensitivity analysis).

2.2.2.3 Antenna gain distributions

Antenna gain distributions are:

- AP Distribution (see Table 12);
- VLP/Client Distribution without Body Loss (see Table 14);
- VLP/Client Distribution with Body Loss (see Table 16).

2.2.2.4 Energy detection thresholds

ETSI EN 303 687 v1.1.1 (section 4.3.6.3.3) [7] defines the following Energy Detection Threshold (EDT) levels (defined at the interface between antenna connector and receiver), above which a channel is determined as occupied channel. The power level is determined by integrating the received power over the channel and then normalising to per MHz power.

The EDT is proportional to the equipment's maximum configured transmit power (P_{\max}):

- For $P_{\max} \leq 14$ dBm: EDT= -75 dBm/MHz
- For 14 dBm $\leq P_{\max} \leq 24$ dBm: EDT= -85 dBm/MHz + (24 dBm – P_{\max})
- For $P_{\max} \geq 24$ dBm: EDT= -85 dBm/MHz

The EDT levels defined above are absolute levels that apply at all times.

2.3 PROPAGATION PARAMETERS

Table 18: Propagation parameters

	Parameter	Options (Note 1)
1.1	Propagation model (Note 2)	Option 1 (Notes 3, 4, 7) Recommendation ITU-R P.1411-12 [9]:
1.2	Shadowing model	- Section 4.1.1. when both the transmitting and receiving stations are below rooftop.
1.3	Clutter loss model	- Section 4.2.1. when one of the stations is located above-rooftop. Option 2 (Notes 4, 7) Recommendation ITU-R P.452-18 [11] ($p = 20\%$ and appropriate clutter heights). If software does not support the in-force version, then Recommendation ITU-R P.452-17 for the median loss ($A_{ht} = A_{hr} = 0$ dB) and Recommendation ITU-R P.2108-1 [12] for the clutter loss are used (Note 6). Option 3 (Note 4) Pathloss and line-of-sight (LOS) probability modelling based on ETSI Technical Report (TR) 138 901, section 7.4 [13].
1.4	Building entry loss (Note 5)	Option 1 Recommendation ITU-R P.2109-2 [3] with 70% 'Traditional' and 30% 'Thermally-efficient' buildings, with a uniformly distributed probability from 1% to 99%, as done in [5]. Option 2 Outdoor-to-Indoor penetration loss modelling based on ETSI Technical Report (TR) 138 901, section 7.4.3 [13].

	Parameter	Options (Note 1)
1.5	Polarisation mismatch	Option 1: 0 dB Option 2: 3 dB on average for aggregate interference [6].
1.6	Body loss	Body loss is assumed to be non-existent for MFCN BSs and WAS/RLAN APs. Body loss of 4 dB is typically assumed for terminals (see Table 6).

Note 1: Models from different options may be combined with proper justification. The software for some ITU-R Recommendations might be for an older version than the one in-force. Interference path loss varies with the option used.

Note 2: The path loss between WAS/RLAN equipment and MFCN terminals (UE) can be modelled as free space path loss. Additional clutter and building entry losses may apply depending on the scenario.

Note 3: ITU-R P.1411-12 Section 4.2.1 applies to distances of $0.055 < d < 1.2$ km (LoS) and $0.26 < d < 1.2$ km (NLoS). Some studies in this Report have applied the NLoS model to shorter paths outside its limit. While these studies are included, the report does not endorse using the recommendation beyond its specified range.

Note 4: The selection of specific line-of-sight (LOS) probabilities or the percentage of locations should be justified, e.g. depending on the scenario.

Note 5: The use of other values of signal loss caused by building materials should be justified with reference to measurement results.

Note 6: Recommendation ITU-R P.2108-1, Section 3.2 ("Statistical clutter loss model for terrestrial paths") is applicable to distances greater than 250 m. Some studies, included in this Report have applied it to shorter paths which are outside this limit. While this Report includes such studies, it does not endorse applying the recommendation beyond its specified range of validity..

Note 7: Benchmarked against urban measurements at 5.85 GHz, with good alignment between measured and predicted loss.

2.4 MFCN DEPLOYMENT ASSUMPTIONS AND MFCN UE AND WAS/RLAN EQUIPMENT SPATIAL DISTRIBUTIONS

There are different considerations on deployment of MFCN and/or WAS/RLANs usage scenarios in the Upper 6 GHz band in this Report. This can affect the assessment on the benefits and drawbacks of different shared use options. Key differences are summarised below to help the reader understand which deployment assumption corresponds to their area of focus:

- If MFCN deployments in the Upper 6 GHz band are assumed to provide
 - both outdoor and indoor coverage/capacity; or
 - mostly outdoor coverage/capacity;
- The associated user requirements for quality of service, including in the uplink (which may also depend on whether lower frequency layers can be aggregated to support indoor coverage or the uplink throughput);
- Whether the Upper 6 GHz band is assumed to support the launch of MFCN 6G deployments;
- Whether the Upper 6 GHz band is assumed to be an additional capacity layer for all MFCN scenarios
- Whether the Upper 6 GHz band is assumed to be an additional capacity layer for all WAS/RLAN scenarios, including for enterprise uses;
- Whether co-channel MFCN UEs and WAS/RLAN equipment are likely to be closely located and transmitting at the same time and therefore would cause interference to each other in practice;
- The level of densification to compensate for an e.i.r.p reduction and achieve the same level of indoor and/or outdoor coverage related to the existing 3.5 GHz macro-cell deployments;
- The feasibility and availability of interworking between MFCN operators and WAS/RLAN in different configurations (residential, corporate, etc.) to offload MFCN indoor data traffic to WAS/RLAN networks instead;
- BFWA, as the fixed component of MFCN, and MFCN mobile broadband are expected to be deployed in the same area. This Report does not assess shared use between MFCN BFWA customer-premises equipment (CPE) and WAS/RLAN.

3 POTENTIAL APPROACHES AND MECHANISMS FOR SHARED USE OF THE SPECTRUM

This section looks at various considerations around shared use of spectrum and covers considerations around MFCN base station *e.i.r.p.* (see section 3.2), sharing mechanisms assuming current standards (see section 3.3), and considerations related to potential new sharing mechanisms (see section 3.4). It also addresses the assessment of MFCN-WAS/RLAN sharing approaches in the Upper 6 GHz (including mechanisms) considered in the studies (see section 3.5).

3.1 CONSIDERATIONS RELATED TO MFCN BS E.I.R.P.

Some studies in this Report analyse the impact of MFCN base station (BS) *e.i.r.p.* in terms of feasibility of shared use of spectrum with WAS/RLAN and the impact on both MFCN and WAS/RLAN coverage/capacity.

The MFCN macro-cellular BS *e.i.r.p.* levels considered in some studies could be different from those considered in the WRC-23 studies, as described in section 2.1.

Higher BS *e.i.r.p.* levels facilitated by AAS BSs with more antenna elements, consistent with currently expected equipment availability, could enable reuse of the existing 3.5 GHz MFCN sites (maintaining the current inter-site distance) without indoor downlink capacity loss. These higher levels of BS *e.i.r.p.* are also considered in some sharing scenarios. Reduced levels of MFCN BS *e.i.r.p.* intended to facilitate supplementary MFCN capacity outdoors with WAS/RLAN indoors are investigated in some other sharing scenarios.

The impact on the quality of MFCN and WAS/RLAN service delivered to end users due to different MFCN BS *e.i.r.p.* levels is also analysed, taking into account the resulting variation of MFCN downlink and WAS/RLAN throughput, MFCN downlink spectral efficiency and MFCN uplink coverage.

Insights from various field trials using prototype equipment are provided in section 5.

The basic assumption is that the MFCN BS "expected *e.i.r.p.* mask" specified at WRC-23 shall be adhered to and the MFCN BSs shall be operated in compliance with the Radio Regulations [40].

3.1.1 Considerations related to outdoor-only MFCN Scenarios with reduced BS *e.i.r.p.*

Some studies in this Report are based on scenarios that aim to provide outdoor-only MFCN coverage (or outdoor MFCN with limited indoor MFCN coverage), and indoor WAS/RLAN, by reducing MFCN BS *e.i.r.p.* levels without MFCN BS densification (reuse of 3.5 GHz existing cellular grid). Existing public MFCN deployments are not currently limited to providing outdoor only coverage. Some challenges and limitations of such scenarios, are detailed further in the sections below along with some possible mitigations including interworking between MFCN and WAS/RLAN and practical implementation issues to be addressed.

3.1.1.1 Impact on indoor MFCN usage

Mobile networks operators have expressed interest in the Upper 6 GHz band for 5G network coverage and capacity expansion and/or for the introduction of 6G MFCN. MFCN usage has a high proportion of indoor usage across all MFCN bands, with recent measurements indicating between currently around 60% and 90% of usage occurs indoors (noting that those indoor users would require greater radio resources than equivalent outdoor users). The majority of this is supported by mid-band spectrum above 2 GHz (including but not exclusively 3.5 GHz – which is indicated in [26] to carry the majority of the indoor 5G traffic).

Consequently, it can be expected that scenarios proposing outdoor-only MFCN coverage (or outdoor MFCN with limited indoor MFCN coverage) with MFCN macro BS would provide limited capacity relief for other congested mid bands. In cases where the upper 6 GHz band is used for the introduction of 6G, such scenarios would limit 6G coverage and capacity in this band.

On the other hand, in these scenarios, where indoor coverage from MFCN is not intended, the interworking between MFCN and non-3GPP networks such as WAS/RLAN may offer a potential solution for offloading some MFCN indoor data traffic.

The 3GPP standards for 5G incorporates several key architectures designed to enable seamless integration of non-3GPP networks with the 5G core network. Since Release 15, the N3IWF (Non-3GPP Interworking Function) architecture (architecture for 5G Core Network with Untrusted Non-3GPP Access) has been available. Release 16 introduced the TNGF (Trusted Non-3GPP Gateway Function) architecture (architecture for 5G Core Network with Trusted Non-3GPP Access) and the ATSSS functionality (Access Traffic Steering, Switching, and Splitting).

These architectures intend to facilitate access from non-3GPP networks to the 5G core while addressing reliability, quality of service and network security considerations. In particular, ATSSS enables MFCN operators to leverage synergies simultaneously between 3GPP and non-3GPP networks, optimizing traffic management with seamless handovers and improving network capacity with a standardised framework.

While standardisation efforts from both the WAS/RLAN and MFCN communities have already resulted in several demonstrators, seamless roaming mechanisms between these networks, among other topics, may still require further implementation efforts to support European-wide deployments. Additionally, beyond spectrum management, there are other challenges expected to be addressed for practical European-wide implementations of the interworking between MFCN (multi-operators and international environments) and WAS/RLAN (multi-users configuration: residential, corporate, etc.) such as cybersecurity, roaming policies, implementation costs, and commercial agreements. This has limited their use and deployment to date. Currently, the choice of access to either MFCN or WAS RLAN largely remains at terminal level and under the control of the user.

3.1.1.2 MFCN service availability and reliability

Scenarios which aim to provide outdoor-only MFCN coverage (or outdoor MFCN with limited indoor MFCN coverage) could result in significant differences in Upper 6 GHz MFCN performance between indoor and outdoor areas. This may affect MFCN operators who are currently competing using licenced spectrum to deliver seamless MFCN service coverage and quality across outdoor and indoor areas, although differences between indoor and outdoor performance already exist.

Where indoor MFCN capacity is provided by interworking with indoor WAS/RLANs, it is assumed that the indoor WAS/RLAN availability, accessibility and performance are sufficient for the overall service quality for by MFCN users. These WAS/RLAN networks may not always be controlled by the MNO. Maintaining connectivity between MFCN and WAS/RLANs when transitioning from 'outdoor areas' to 'indoor areas' (and vice versa) could also be challenging, potentially impacting the quality of some MFCN services.

In practice, variable building entry losses depend on construction materials (modern building practices, driven by energy efficiency goals, are increasingly introducing materials that also increase RF isolation) and architectural design and do not result in perfect isolation between indoor WAS/RLAN and reduced power outdoor MFCN. This can lead to interference to both applications.

Whilst MFCN is intended to operate in an interference-limited environment, there are techniques (such as network planning, power control, inter-cell interference rejection, inter-cell signal combining and interference cancellation) that an operator could use to manage interference in its network. However, inter-system interference to MFCN from WAS/RLAN systems is not manageable in the same way.

This Report explores various detection techniques which may potentially be used by MFCN and/or WAS/RLAN to attempt to mitigate these inter-application effects.

3.1.1.3 Deployment of MFCN coverage enhancement solutions

Most studies in this Report assume MFCN deployment on macro-cell grids, they do not consider the impact of MFCN operators deploying coverage enhancement solutions such as small cells, repeaters, or indoor coverage solutions in response to reduction in *e.i.r.p.*

Deployment of these MFCN coverage enhancement solutions could result in practice in indoor coverage levels similar to what would have been achieved by not reducing MFCN base station *e.i.r.p.* levels..

3.1.2 Considerations related to indoor Wi-Fi use with full power BS e.i.r.p.

Some studies in this Report are based on scenarios that aim to provide indoor and outdoor MFCN coverage from outdoor MFCN BS, which is the typical way of deploying and offering MFCN services in the current MFCN harmonised bands. The implications are detailed further below as the resulting challenges and limitations could impact decisions on WAS/RLAN deployments in the band.

3.1.2.1 Service Availability

It is expected that over time building entry losses would increase to some degree as thermal efficiency of buildings is improved. This would lead to higher building radio frequency isolation between indoor and outdoor users and networks (WAS/RLAN indoor, MFCN outdoor). However, the level of isolation is expected to remain insufficient to allow WAS/RLAN networks to be useable in large parts of the buildings due to interference from outdoor MFCN BS operating at full power.

Even in planned and centrally managed WAS/RLAN networks such as enterprise and industrial environments, which are designed to meet specific user requirements, the WAS/RLAN radio resources management could be unable to compensate for potential interference from outdoor MFCN with full power. This could result in reduced WAS/RLAN channel widths and reduced WAS/RLAN network capacity.

More broadly, any co-channel MFCN roll out nearby to a building where a WAS/RLAN is deployed could cause interference and WAS/RLAN to vacate the channel where it detects an MFCN signal. This lack of certainty on WAS/RLAN spectrum availability could therefore affect WAS/RLAN designs and customer commitments, whether or not MFCN is deployed nearby to the building in question.

3.1.2.2 Effect on WAS/RLAN deployment scenarios

WAS/RLAN deployment scenarios could include the following:

- Residential networks, typically used in homes indoors.
- Professional or high-density deployments for enterprise and industrial networks that can cover indoor and outdoor public and private networks
 - in airports, university campuses, stadiums, hospitals, and schools
 - private networks for industrial and enterprise deployments
- VLP which can operate in both indoor and outdoor environments and is suited for applications such as augmented reality (AR) and virtual reality (VR).
- WAS/RLAN used to support Fixed Wireless Access (FWA) services, particularly in rural areas where fibre connectivity is not available.

Section 2.2 describes the WAS/RLAN parameters used in some of the studies of this Report. It focuses on WAS/RLAN deployments during the maximum internet traffic busy hour (in the evening, where the maximum aggregate interference is expected).

Sharing scenarios that restrict WAS/RLAN use to indoors may limit the feasibility of certain WAS/RLAN deployments. Note that in the WAS/RLAN model of section 2.2, WAS/RLAN deployed outdoor are either VLP (1% of active WAS/RLAN) or unintentional outdoor LPI Client (0.21% of active WAS/RLAN).

3.1.3 Considerations related to WAS/RLAN VLP deployments scenarios with full power MFCN BS e.i.r.p.

Some studies in this Report considered indoor and outdoor VLPs without any additional sharing mechanisms. It can be noted that that VLP devices are primarily consumer devices similar to MFCN UEs in their uses.

MFCN uses radio protocols and emission limits to avoid/manage UE-to-UE and UE-to-BS interference. However, similar measures are not implemented in current VLPs. Further consideration of interference risks from VLP to MFCN may be needed as a result.

3.2 TECHNICAL AND REGULATORY ASPECTS OF WAS/RLAN SPECTRUM SHARING AND COEXISTENCE: LESSONS LEARNED AND NEXT STEPS

3.2.1 Harmonised technical conditions (radio regulatory framework)

In the 2.4 GHz, 5 GHz and lower 6 GHz (5945-6425 MHz) bands, WAS/RLAN equipment operates under established regulatory frameworks. The current harmonised technical and operational conditions are designed to enable WAS/RLAN systems to share spectrum with other users and have been developed based on technical studies from CEPT. These studies addressed coexistence with a range of incumbent services and applications, such as short-range devices, radars including meteorological (MET) radars, telemetry, satellites, and fixed services.

These harmonised conditions include, as appropriate, technical and operational requirements such as e.i.r.p., indoor-only usage restrictions, Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS) depending on specific frequency bands and the incumbent services to be protected. These regulatory measures are intended to prevent harmful interference to incumbent users and are implemented in ETSI Harmonised Standards based on CEPT deliverables.

3.2.2 Existing ETSI Harmonised Standards

ETSI EN 300 328 [24] (2.4 GHz), ETSI EN 301 893 [27] (5 GHz) and ETSI EN 303 687 [7] (lower 6 GHz) are the harmonised standards in the respective highlighted bands. In addition to the implementation of the above regulatory measures, WAS/RLAN Harmonised standards specify channel access mechanisms such as Listen-Before-Talk (LBT) as a way of providing WAS/RLAN intra system spectrum access and sharing mechanisms. Energy detection (ED) enables WAS/RLAN to share the spectrum in the presence of interference from non-WAS/RLAN systems.

The current channel access mechanisms specified in the existing WAS/RLAN harmonised standards were not designed to support sharing with potential MFCN use as explored in this Report. Therefore, further standardisation efforts may be required to support shared use between WAS/RLAN and MFCN systems, following further recommendations from CEPT. Any additional sharing mechanisms necessary to protect MFCN would also have to be defined in the appropriate Harmonised Standard for any proposed WAS/RLAN use in the Upper 6 GHz band including any specific requirements needed such as detection criteria, mitigation techniques, user access restriction (i.e. ensuring that functionalities specific to sharing with MFCN cannot be circumvented by the end user) including relevant conformance testing.

3.2.3 Maintaining confidence among spectrum users

For example, to enable operation in parts of the 5 GHz band, WAS/RLANs are required to employ an additional Dynamic Frequency Selection (DFS) mechanism to protect radar operation including MET radars in 5.6 GHz. DFS requires that when a radar signal is detected, the WAS/RLAN shall stop transmitting on the channel for a defined period. Occurrences of interference to MET radars from non-compliant or illegally modified WAS/RLAN devices have triggered analysis from Joint Research Centre (JRC) of the European Commission identifying various actions in order to reduce the risk [42]. In particular, this led to the harmonised standard being updated to contain a specific user access restriction section that now prohibits any deactivation of DFS in accordance with the last update of regulation. Additionally, at this stage, some MET organisations are funding the migration of their radars from 5.6 GHz to bands without WAS/RLAN operation.

As a result, when investigating a practical implementation of a shared use between MFCN and WAS/RLAN, CEPT and ETSI should take care that compliance to any additional mechanism (such as enhanced detection mechanisms) is adequately reflected in harmonised standards (such as avoiding deactivation by users).

3.2.4 Lessons learnt on service availability

Experience has also shown that mobile network operation in bands adjacent to WAS/RLAN can lead to interference issues. In some cases - and not only during special events - interference from MFCN base stations has impacted WAS/RLAN applications. Due to WAS/RLAN users and service requirements, this has resulted in deactivation of the affecting MFCN stations.

When assessing practical implementation of any shared use mechanisms between MFCN and WAS/RLAN, both MFCN and WAS/RLAN technical conditions and user requirements (such as service availability also addressed in section 3.2.1.1) should be taken into account.

3.3 CONSIDERATIONS RELATED TO SHARING MECHANISMS ASSUMING CURRENT STANDARDS

This section explores sharing approaches with the assumption that sharing mechanisms are based on current standards, as available at the time of writing this Report .

WAS/RLAN's multiple access protocols allow WAS/RLAN radios to operate in a decentralised manner and in competition with an indeterminate number of other co-channel WAS/RLAN pieces of equipment. WAS/RLAN radios assess the occupancy of the channel by sensing the presence of received signals over the air (Energy Detection). If the received signal powers are above specific thresholds (e.g. the Energy Detection Threshold, EDT), the WAS/RLAN radios defer their transmissions by a random amount of time until the channel is assessed to be free and available (this is also referred to as "listen-before-talk" or LBT for short).

3.3.1 Detecting MFCN with current WAS/RLAN energy detection mechanism

The WAS/RLAN energy detection mechanism could potentially be used for detecting channel usage by MFCN, leading to deferring of WAS/RLAN transmission upon detection. Studies explore the shared use benefits and challenges of this mechanism. Some studies investigate beyond the existing framework, including parameter adjustments like detection thresholds to help investigate and explore the feasibility of potential sharing mechanisms.

However, using the EDT may not always work. Figure 2 shows an example of when the WAS/RLAN sensing mechanisms are insufficient to protect the MFCN UE because the MFCN base station signal level at the AP is lower than the EDT. Here, the AP is a "hidden node" and could cause interference to a nearby MFCN UE, or even the MFCN BS, depending on the geometry.

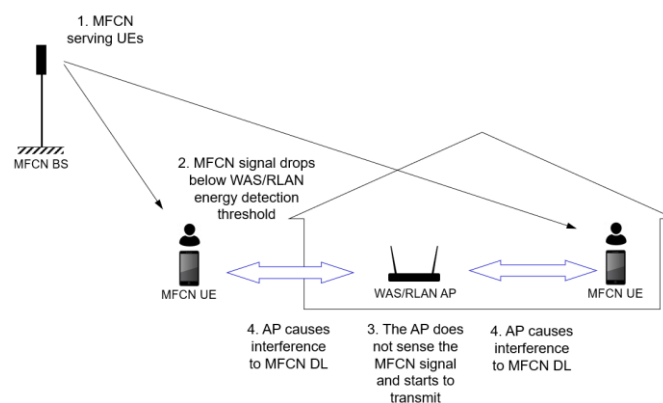


Figure 2: Interference path from LPI WAS/RLAN AP into MFCN UE

3.3.2 Generic sharing approaches

Generic sharing approaches already implemented in other frequency bands with either WAS/RLAN or MFCN could be further investigated if needed and as appropriate:

- Band-split/frequency separation: Portions of the Upper 6 GHz band are allocated to each technology (a comparable example is WAS/RLAN using only part of the 5 GHz bands due to other uses within those frequencies). Adjacent band issues and the size of the band dedicated to each technology are critical aspects of this approach. These considerations have not been addressed in this Report and require further analysis. Usage conditions of each application with other services operating co-channel or adjacent channel are subject to other ECC Reports (see ECC Report 364 [22] for studies on WAS/RLAN and the

ongoing studies towards a new ECC Report on study and assessment of coexistence and compatibility of MFCN in upper 6 GHz band with incumbent spectrum users;

- Geographical separation: MFCN is given priority in some geographical areas while WAS/RLAN is given priority in others. This could be an urban/rural split for example. However, in drafting this Report, it has been assumed that both systems operate in the same geographical area (areas with high population density corresponding to the priority deployment areas for both MFCN and WAS/RLAN (see Study B1 in section 4.8). In practice, there is no example of geographical separation approaches implemented in the WAS/RLAN harmonised regulatory framework. Concerning MFCN, there are examples in place such as to protect the Radio Astronomy Service (RAS) or satellite Earth stations;
- Time split: In addition, time split (different applications receive priority at different times, e.g. day/night or for a certain time during an event) has been mentioned during the drafting of this Report. This approach requires a careful analysis of the needs and consequences of unavailability of service operation during a given period of time. Dedicated mechanisms are also required in order to not use the band when the other application is using the band or to vacate definitively the relevant band in case of higher needs than expected for the application having the priority. Mechanisms implementing this approach have to be standardised and shall be part of the sharing requirement in particular due to a possible risk of deactivation of the mechanism by the users in order to continue to operate the application beyond the time permitted. This is a source of complexity and risks of interferences .

Possible implementations of geographic separation, frequency separation or separation in time, including in a semi dynamic environment, have been initially explored in this Report as possible sharing actions that might be taken by each technology upon awareness (via sensing, cross-technology signalling or databases) of the other (see section 3.4). Due to free circulation and use of equipment, the practical implementation of these sharing actions requires harmonised and standardised approaches which have not been studied in detail in this Report. In case of separation in time, the relevant consequences of unavailability of service operation during a period of time has not been addressed in this Report. Nevertheless, significant periods of unavailability or a need to vacate the band permanently in a location after an initial period of time sharing can have a negative impact on the investment and future usage of the band.

3.3.3 Location awareness

Where the locations of both APs and priority users are known, there may be opportunities to enable sharing based on higher level protocols. While it is frequently assumed that the location of WAS/RLAN access points (APs) is unknown and that their operation is uncoordinated, this is not the case for some scenarios.

For example, enterprise networks are managed, the location of the APs are known (and their configurations can be adapted to support a variety of operational requirements). In residential environments, the majority of APs are provided and managed by Internet Service Providers (ISPs), and their physical locations are generally known to a reasonable degree of accuracy. Further, protocols such as Broadband Forum (BBF) TR-069 and TR-369 allow ISPs to maintain visibility and control these WAS/RLAN APs.

If information about the location of nearby priority users- such as MFCN base stations or RAS sites -is also available, enterprise network operators and ISPs could use these protocols to adjust the operational parameters of the WAS/RLAN APs within areas where harmful interference could potentially occur, as discussed in section 3.5.

Studies in this Report did not differentiate between the various types of WAS/RLAN deployments, and further work might be required.

3.4 CONSIDERATIONS RELATED TO NEW SHARING MECHANISMS

Potential new sharing mechanisms could be developed relying on the following aspects.:

- 1 **Cross-technology awareness.** Allow MFCN to understand that WAS/RLANs are present and/or vice-versa. Cross-technology awareness may include mechanisms based on sensing, signalling and database. Detection may be necessary in some scenarios for identifying active systems and managing coexistence in the spectrum. This aspect has been considered in this Report. It is to be noted that signal propagation challenges like hidden terminals and dynamic environments can impact the effectiveness of these

detection techniques, which is an aspect that has not been studied in this Report. Sensing technologies can be supported with the addition of databases to help share information between technologies if necessary. See section 3.4.1 for further details.

- 2 **Prioritisation.** In most cases a priority to one technology or another in a particular location, frequency or time resource would likely have to be applied. A minimum amount of guaranteed spectrum is likely to be required for both networks to support investment. Additional spectrum access could be on a more opportunistic basis when the other network is not present. Some studies in this Report have assumed priority of one technology over the other (as a hypothesis for those studies), but this aspect is related to policy decisions, which are not in the scope of this Report.
- 3 **Possible spectrum organisation.** The impact on a system depends on the agreed action that MFCN or WAS/RLAN must take as part of an interference mitigation mechanism. This can range from leaving a channel, reducing transmission power, or continuing operation if the interference risk is very low.

The potential for unacceptable interference to one or the other system at the boundary resulting from the implementation of an MFCN and WAS/RLAN split (be it in frequency – spectrum adjacency, in time – time adjacency, or in space – locations adjacency) is of importance, and would need to be addressed appropriately in practice.

A list of input documents with further details on the awareness mechanisms discussed below is available [here](#).

3.4.1 Cross-technology awareness

Three main approaches can be used to allow awareness between MFCN and WAS/RLANs:

- a) Schemes based on sensing for monitoring the spectrum to detect active usage and interference in the shared frequency bands. Sensing techniques such as energy detection, modulation detection, pattern detection can be used to measure and analyse signals, providing insights into spectrum occupancy. Note that, the selection of a specific sensing scheme may have an impact on technology neutrality.
- b) Schemes based on signalling require the exchange of signals between devices from different systems, facilitating cross-technology interaction. The exchange may be unidirectional, with one technology using broadcast transmissions to advertise its presence to the other technology, or it may be bidirectional, assuming a two-way communication between devices from different technologies. Another solution is to employ a third party, as in the case of database-assisted coordination. To be able to transmit or receive other technology signals, new capabilities may be needed in one or both technologies compared to existing standards. Changes may include supporting modulation schemes, preamble structures, and time/frequency signal structures of the other technology. The signalling-based schemes may involve only a sub-set of devices (for example only WAS/RLAN APs and MFCN BSs) or involve all devices. The cases where MFCN UE is involved are referred to as “smartphone-assisted coordination”. All proposed cross-technology signalling schemes would have impacts on implementation for either or both MFCN and WAS/RLAN devices, depending on the specific proposal. For example, specific hardware implementations may be needed, and a requirement to periodically search for specific signals could lead to increased power consumption, which could be a concern for battery-powered or portable devices. All these schemes would need to be standardised, harmonised and tested for compliance, taking into account technology neutrality. Certain aspects may not be fully implemented in all devices, particularly user equipment that is transiting through Europe from other regions, depending on how any cross-technology signaling scheme is implemented. Also, equipping devices with the necessary functionality and introducing these to the market would take some time. It should be noted that any cross technology signalling framework would need to be maintained in the design of subsequent generations of WAS/RLAN and MFCN technologies.
- c) Schemes based on databases where one or both technologies access a database in order to request transmit parameters, which would depend on the information provided by the radio equipment/devices in their query of the database, including location of the requesting device.

3.4.1.1 Frequency schemes for cross-technology signalling

Note that a frequency harmonisation scheme between MFCN and WAS/RLAN systems may be required or at least beneficial to the effectiveness of some cross-technology signalling (XTS) mechanisms. The principle is illustrated in Figure 3 and Figure 4, in the case of IEEE 802.11 based WAS/RLAN systems. The illustrated example is based on the assumption that IEEE 802.11bc [25] signals are transmitted by IEEE 802.11 based APs operating with primary channels on the pre-defined 20 MHz preferred scan channel (PSC) frequencies. A common carrier frequency block arrangement would ensure that each MFCN carrier overlaps with the primary channel of any IEEE 802.11 based AP with bandwidth up to 80 MHz that might operate on some frequencies that are common with that MFCN, and therefore might facilitate the IEEE 802.11WAS/RLAN equipment to more easily detect any cross-technology signals.

Cross technology signals might be based on energy or patterns (see DFS), MFCN-based signals for cross-technology signalling, and/or WAS/RLAN-based signals for cross-technology signalling.

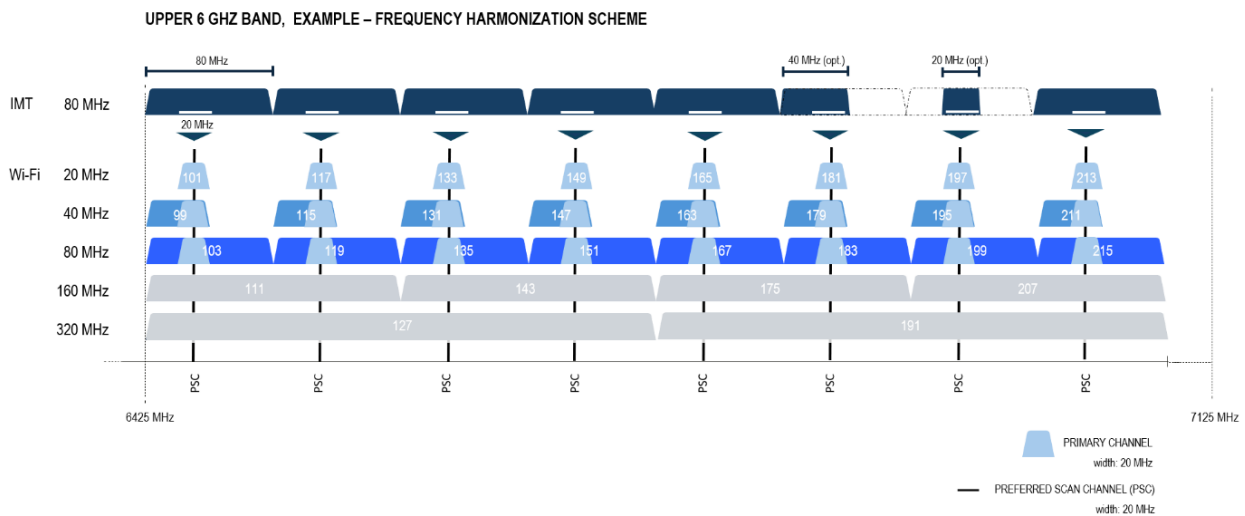


Figure 3: Illustrative example of a carrier frequency block arrangement between MFCN and IEEE 802.11-based WAS/RLAN systems in the Upper 6 GHz band

This illustrative arrangement might also reduce cases where MFCN carriers would be placed in ways that do not overlap with some IEEE PSC channels, as decoding of cross-technology signalling by WAS/RLAN would be significantly more complex.

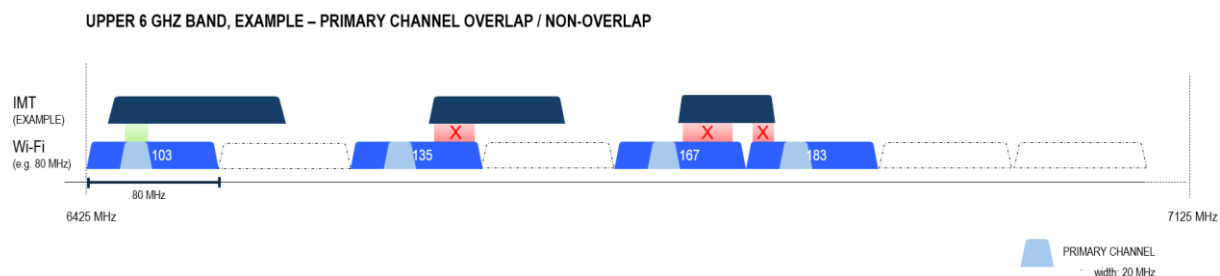


Figure 4: Illustrative example of a carrier frequency block arrangement between MFCN and IEEE 802.11-based WAS/RLAN systems with/without overlap of MFCN carriers with WAS/RLAN control channels

The illustration above only shows some possible examples of XTS frequency block alignment. However, MFCN channelisation could be different depending on the available number of MNOs in a given country. Therefore, specific details on the frequency locations of any cross-technology signalling, and their relation to MFCN channelisation would require work at standard level, e.g. at ETSI and IEEE. In particular, a robust solution would need to be defined to account for different possibilities in terms of MFCN and WAS/RLAN channelisation.

A benefit of the frequency alignments of the type discussed above would be the potential to enable or optimise possible XTS mechanisms in certain deployment scenarios, but a potential drawback is the constraints that may be imposed on the MFCN block sizes and positions assigned to mobile network operators in the spectrum authorisation process.

In this Report, studies A3 (section 4.7), C1 (section 4.1), D4 (section 4.1), D1 (section 4.2), D9 (section 4.3) and D10 (section 4.4) investigated different aspects related to the use of open-loop cross-technology signalling for sharing.

3.4.1.2 WAS/RLAN awareness of MFCN BS

Transmission of IEEE 802.11bc frames from MFCN BSs

In this mechanism for WAS/RLAN awareness of MFCN, the MFCN BS broadcast a signal based on the IEEE 802.11bc standard as a physical layer between the two technologies. This is illustrated in Figure 5. Being specific to Wi-Fi technology based on IEEE standards, 802.11bc signalling is not technology neutral, and so the term “Wi-Fi” rather than “WAS/RLAN” is used (given that not all WAS/RLANs operate based on IEEE 802.11 technologies).

A Wi-Fi AP operating in the Upper 6 GHz band would receive and process the messages, as specified by the existing IEEE standard. The signalling would in principle enable Wi-Fi APs to detect the presence of MFCN and to trigger interference mitigating action. The reception and processing of IEEE 802.11bc messages by Wi-Fi STAs is not considered as part of this mechanism, however further investigation could be carried out for the case of STAs operating without AP supervision.

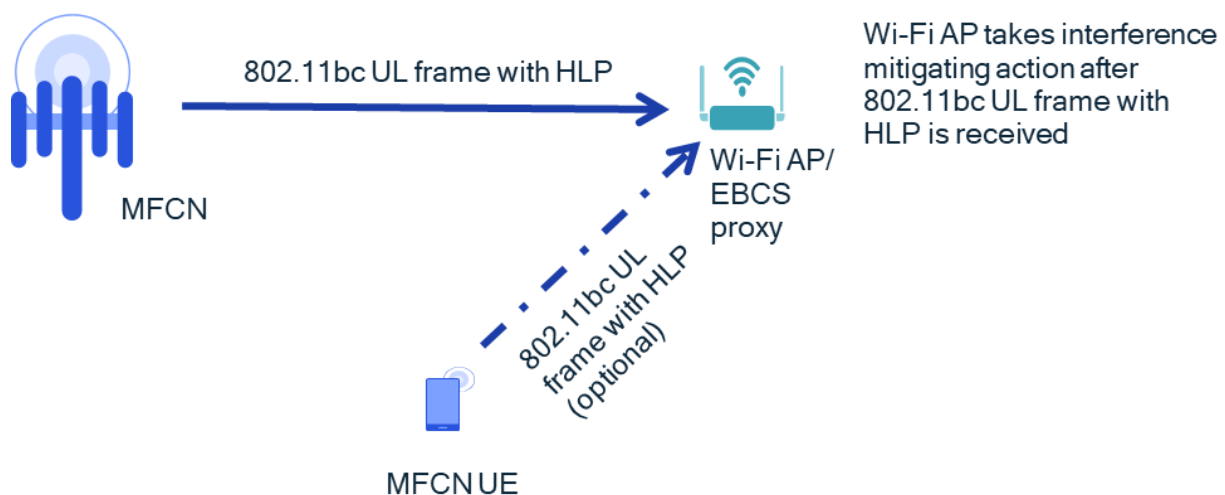


Figure 5: Wi-Fi AP interprets IEEE 802.11bc message and takes interference mitigating action (for example, vacates the MFCN channel after detection)

The overhead of transmitting IEEE 802.11bc messages from MFCN BSs can be small. The message can be transmitted over a single 20 MHz channel (or if desired duplicated over multiple 20 MHz channels). Assuming, a 6 Mbit/s rate over a 20 MHz channel (spectral efficiency of 0.3 bit/s/Hz), relatively large sized message of 3000 bits can be transmitted during a single 5G slot, which is sufficient to carry the necessary information. The periodicity of these transmissions can be fully flexible and coverage can be controlled by the transmission periodicity and the beam selection. The content of the message is also flexible and may or may not be the same across different channels.

Note that IEEE 802.11bc is a finalised standard which can be supported by Wi-Fi6 hardware via software changes only, minimising the impact on Wi-Fi design and implementation. The IEEE 802.11bc signals would need to be included in the design of future generations of Wi-Fi technologies deployed in the Upper 6 GHz band. A potential drawback of the proposed IEEE 802.11bc mechanism, for example compared to the other solution based on 3GPP SSB transmissions by MFCN BSs (see next section), is that the signal-to-interference-

plus-noise ratio (SINR) requirements for decoding of IEEE messages are higher than the requirements for the decoding of 3GPP SSB.

According to the IEEE 802.11bc standard, UL frames received may be validated at the Wi-Fi AP by the authentication proxy. If the authorisation fails, the received message can be ignored (e.g. if the message source was not authorised to transmit XTS).

The higher SINR requirement results in greater possibility of hidden-node interference scenarios. However, since most MFCN UEs (smartphones) implement Wi-Fi technology, the proposed approach could also accommodate IEEE based signalling from the MFCN UEs. IEEE 802.11bc transmissions from MFCN UEs could largely reduce the occurrences of missed detection due to hidden nodes, which would come at the cost of additional power consumption in the MFCN UEs. The use of MFCN UEs to transmit IEEE 802.11bc is described in section 3.4.1.3.

Depending on the sharing framework details, the mechanism would need to be implemented in some (e.g. MFCN BSs and WAS/RLANs APs) or in all MFCN and WAS/RLAN equipment which are intended to operate in the Upper 6 GHz band. Note that the mechanism would also need to be implemented in WAS/RLANs not based on IEEE 802.11 technologies. Both the transmissions of IEEE 802.11bc signals by MFCN equipment, and the ability of WAS/RLAN equipment to detect and decode the IEEE 802.11bc signals and take appropriate action need to be standardised, harmonised and tested for compliance. It should be also guaranteed that the behaviour standardised and assessed by conformance testing cannot be modified by the end users.

Also, in case the deployment of MFCN in a specific geographic area arrives at a later stage compared to the introduction of Wi-Fi equipment in the same area, the Wi-Fi user would be subject to a variation in performance over time due to the need to vacate part of the spectrum once MFCN are deployed. However, whether this potential change in performance can be perceived by the end users depends on many factors (e.g. required demand for Wi-Fi and MFCN traffic, density of MFCN deployments, etc.).

This mechanism was investigated in studies A3 (section 4.7), D9 (section 4.3), D10 (section 4.4).

WAS/RLAN decoding of 3GPP SSB signals

This mechanism consists of WAS/RLAN equipment detecting and decoding 3GPP 5G NR synchronisation signal block (SSB) pilot signals, as transmitted by MFCN BSs in Upper 6 GHz channels as part of their normal operation. This is illustrated in Figure 6. Note that SSB is not technology neutral and belongs to the 3GPP family of MFCN standards. Upon successful decoding of these signals, WAS/RLAN equipment would be required to cease transmissions in the relevant channels, or take alternative action in order to avoid interference to MFCN.

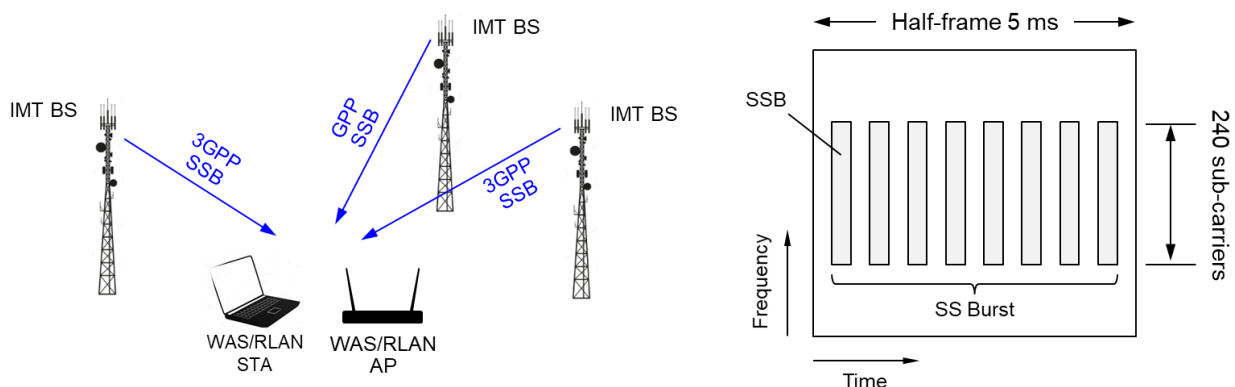


Figure 6: SSB transmissions within a half-frame in 5G NR for the proposed mechanism

As illustrated in Figure 6, SSBs are transmitted in groups – known as SS Bursts – which occupy a 5 ms half-frame. Note that the SSBs in an SS Burst are not repetitions, as they each contain different information content. For the 6 GHz band, MFCN BSs have the option of transmitting between 1 and 8 SSBs in each SS Burst. The SS Bursts themselves can have periodicities of 5, 10, 20, 40, 80 or 160 ms. The SS Burst periodicity is typically

20 ms or less. SSBs occupy 4 consecutive OFDM symbols in the time domain and utilise 240 adjacent subcarriers (equivalent to 20 Resource Blocks) in the frequency domain.

This mechanism would in principle allow WAS/RLAN equipment to detect the presence of MFCN at lower signal level than when using energy detection. That said, in practice, it is always possible that some WAS/RLAN equipment might be hidden from MFCN BSs due to obstructions and shadowing, resulting in cases of missed detection.

The Upper 6 GHz MFCN BSs would be required to transmit 5G NR SSB pilot signals. As a result, the proposed potential mitigation mechanism would be transparent to the operation of 5G MFCN, but would require the 5G NR SSB signals to be included in the design of 6G and future generations of MFCN technologies deployed in the Upper 6 GHz band.

This mechanism would require that WAS/RLAN equipment to include the necessary radio hardware to decode the SSBs. This may not pose an issue for WAS/RLAN equipment embedded into smartphones, as they already support access to MFCN UE functionality, but would have additional impact on devices that do not have MFCN functionality. The implementation of protocols to decode SSBs and to subsequently take appropriate action, would require changes to the software and firmware in the WAS/RLAN equipment. Moreover, the required periodic search for SSBs would additionally lead to increased power consumption, which could be a concern for battery-powered or portable WAS/RLAN devices.

The functionality for WAS/RLANs to decode SSBs and to take subsequent action would need to be standardised, harmonised and tested for compliance. It should be also guaranteed that the behaviour standardised and assessed by conformance testing cannot be modified by the end users. Also, equipping WAS/RLAN devices with the necessary functionality and introducing these to the market will take some time.

This mechanism was investigated in studies C1 (section 4.1), D4 (section 4.1), D1 (section 4.2), D10 (section 4.4).

Transmission of an on-off keying (OOK) signal from MFCN BSs

Cross-technology signalling could be enabled by a dedicated type of pilot signal which would aim to provide a higher degree of flexibility than the solutions above.

Only limited information would be required to be contained within a pilot signal, i.e. to indicate the presence of an MFCN transmission, its centre frequency and bandwidth, and further information if cybersecurity requirements are addressed. The required data-rate may therefore be lower than for a traffic signal. Taking advantage of this, the pilot signal could use very basic encoding, e.g. on-off keying (OOK) with Manchester encoding. This would have the advantage that the WAS/RLAN could successfully decode the signal as long as it partially overlaps with the MFCN transmission, independently of the individual bandwidths and centre frequencies of the two systems. However, channel alignment remains beneficial when deciding which action to take upon detection of an MFCN signal.

The use of OOK may be more easily implementable than processing signals with higher-order modulation. Better detection could be achieved with increased bandwidth overlap, due to receiving more signal power. Further work would be required to determine a suitable detection threshold for this mechanism, which could be specified in relevant regulations/standards.

The specific implementation on where to include the pilot signal within an MFCN transmission in time and frequency domain could be made flexible, so that the MFCN operator could determine how much resource to dedicate to this signal, based on a trade-off of data-rate versus protection from interference. The resulting variation of the spectrum availability for WAS/RLAN could be detrimental. As for other detection mechanisms, implementation in MFCN downlink broadcast beams is assumed to provide better detection reliability than traffic beams.

Should the goal be to ensure maximum detection probability and to avoid hidden node problems, the pilot signal transmissions could be enabled on both MFCN downlink and uplink, i.e. base stations and user equipment, and reception could also be requested by all WAS/RLAN devices, i.e. access points and client devices. In the latter case the client device would need to inform the access point of the reception of the pilot signal.

This mechanism would need to be included in relevant standards for both MFCN and WAS/RLAN. This would present complexity for both systems compared to other approaches which are already standardised by one system. Standardisation, harmonisation and compliance testing are considered necessary in order to provide the minimum requirements for a common mechanism that can be transmitted by MFCN and successfully decoded by WAS/RLAN.

As noted, further work would be needed to develop this mechanism in particular on the detection threshold and mitigating actions, including for cases where MFCN and WAS/RLAN channels are not aligned. In addition, cybersecurity aspects should be considered in order to avoid spoofing of the signal and DDoS attacks, while noting this would introduce additional complexity.

Smartphone assisted awareness of the presence of MFCN BSs

Assuming that MFCN has priority over WAS/RLAN (in a given location/duration/frequency band), then this potential sharing mechanism is based on the idea that MFCN UEs could effectively act as geographically distributed sensors for the purpose of reporting on the presence of MFCN BS in channels in the Upper 6 GHz band.

The successful operation of this awareness/signalling mitigation mechanism would rely on two main elements:

- 1 the ability of WAS/RLAN equipment to decode special “channel unavailable” signals that would be repetitively transmitted by nearby MFCN UEs.
- 2 the significant deployment of MFCN UEs, as the higher the number of devices, the higher the probability of successful signalling and detection.

This potential sensing mechanism could in principle result in efficient sensing given a sufficiently large number of Upper 6 GHz MFCN UEs. However, the unpredictable behaviour of radio propagation means that in practice it is almost certain that some WAS/RLAN devices would fail to decode the correctly transmitted “channel unavailable” WAS/RLAN signals, resulting in continued WAS/RLAN transmissions. Accordingly, the viability of such a mechanism as a standalone sharing mechanism is by no means certain:

- The sensing mechanism would introduce complexities in the design and architecture of RF hardware in MFCN UEs. Such functionality would also require changes to the software and firmware in the MFCN UEs. From a purely radio hardware perspective, the impact on WAS/RLAN would depend on whether the signal transmitted is a Wi-Fi formatted message or a new message format;
- The sensing mechanism would be accompanied with additional power consumption due to the continuous transmission of special “channel unavailable” WAS/RLAN signals by the MFCN UEs, and their reception by WAS/RLAN equipment;
- The MFCN UE transmission of special “channel unavailable” WAS/RLAN signals would need to be specified through collaboration between the relevant WAS/RLAN and MFCN standards bodies.

Further details of this mechanism can be found in the full study (the attachments can be found [here](#)).

3.4.1.3 WAS/RLAN awareness of MFCN UE

Transmission of an IEEE 802.11bc from MFCN UE

As explained in 3.4.1.2, IEEE 802.11bc standard can be used as physical layer for cross-technology signalling between the WAS/RLAN and MFCN technologies.

In the framework presented in this section, the MFCN UE would transmit IEEE 802.11bc UL frames. All other elements of the framework do not change with respect to the overview already presented in the corresponding section on WAS/RLAN awareness of MFCN BSs, and there are no changes to the WAS/RLAN equipment behaviour with respect to the required operations and behaviour described in that section.

Since most MFCN UEs (in particular, smartphones) implement Wi-Fi technology, transmission of IEEE 802.11bc signals from MFCN UEs could reduce the occurrences of missed WAS/RLAN detection of the MFCN deployments due to hidden nodes, at the expenses of additional power consumption at the MFCN UE.

All the observations expressed in 3.4.1.2 for the transmission of an IEEE 802.11bc from MFCN BSs, related to implementation, equipment standardisation, harmonisation for compliance testing, market penetration, and timing considerations apply in the same way to this mechanism as well.

This mechanism was investigated in study D9 (see section 4.3).

Transmission of an on-off keying (OOK) signal from MFCN UEs

(See section 3.4.1.2). This mechanism was not investigated in any studies of this Report.

Smartphone assisted awareness of the presence of MFCN UEs

(See section 3.4.1.2). This mechanism was investigated in study D9 (see section 4.3).

3.4.1.4 MFCN awareness of WAS/RLAN

Smartphone assisted awareness of the presence of WAS/RLAN

This potential sharing mechanism is based on the idea that MFCN UEs could effectively act as geographically distributed sensors for the purpose of detecting the presence of WAS/RLANs in channels in the Upper 6 GHz band.

The successful operation of this sensing mechanism would rely on the ability of MFCN UEs to detect and decode the WAS/RLAN signals – with a low probability of false negatives – through the decoding of received WAS/RLAN transmissions.

The proposed mechanism would require that MFCN UEs include the necessary radio hardware to decode the WAS/RLAN signals. This may not be an issue as most MFCN UEs (in the case of smartphones) include WAS/RLAN radios. The implementation of protocols to take appropriate actions upon decoding of a WAS/RLAN signal would require changes to the software and firmware in the MFCN UE. The required periodic search for WAS/RLAN would require additional power consumption, which could be a concern for portable devices.

Further details of this mechanism can be found in the full study (attachments can be found [here](#)).

3.4.2 Possible spectrum organisation

This section discusses the impact of various sharing actions that might be taken by each technology upon awareness (via sensing, cross-technology signalling or databases) of the other.

3.4.2.1 Frequency separation

Frequency separation is where MFCN and WAS/RLAN transmit in different portions of the spectrum. This can result either in a fixed, semi-dynamic or fully dynamic frequency split of the band.

A fixed band split requires no sensing or cross-technology signalling mechanism, as the frequency separation mechanism remains static: MFCN and WAS/RLAN operate in different parts of the frequency band. The simplest implementation of frequency band partitioning would explicitly assign and harmonise different fixed portions of the Upper 6 GHz band to MFCN and WAS/RLANs respectively. How to partition the Upper 6 GHz according to spectrum needs for both MFCN and WAS/RLAN has not been addressed in this Report.

Potential issues of adjacent band coexistence should be investigated in a band split approach as well as the size of the band dedicated to each technology. These issues and how to address them have not been considered in this Report as the flexible options depend on assessment of their practical implementation.

Another approach is an opportunistic band split where each application would be allowed to opportunistically access the portion of the band assigned to the other application, if it does not cause undue interference to the other application. Such an opportunistic band split could be based on sensing (enhanced and adequate

detection mechanism), or cross-technology signalling, using smartphones, database or other mechanisms. It may be particularly beneficial in geographical areas, or parts of areas, where only one application is present due to incumbents, demand, or deployment timescales.

A variation to the aforementioned opportunistic band split could be to deploy, for example, MFCN small cells with very low *e.i.r.p.* (e.g. 40 dBm/100 MHz) outdoors in the portion of the band assigned to WAS/RLAN, with WAS/RLAN restricted to indoor only usage (restricting the use of VLP outdoors).

3.4.2.2 Separation in time

In time separation, MFCN transmit at certain times while WAS/RLAN transmit at other times. This effectively results in a static or dynamic time split between the two technologies.

Time-split may occur at the coarse scale (e.g. authorising one application for a few days, or a few hours during a day) or at a granular frame level.

At frame level, two mechanisms can be considered: WAS/RLAN transmit in MFCN UL timeslots or MFCN avoid specific radio frames.

There are significant drawbacks of frame level separation in time for both WAS/RLAN and MFCN:

- WAS/RLAN must adopt an MFCN frame-like transmission pattern;
- It requires an alignment and synchronisation of the MFCN and WAS/RLAN frames and may also impact the feasibility of implementing ultra-low latency (ULL) applications (by both MFCN and WAS/RLAN);
- The current MFCN frame transmission patterns in the 3.5 GHz band are heavily DL oriented, i.e. only around 25% of the slots may be UL slots, and would result in severe spectrum access limitation for WAS/RLAN if these were used in the Upper 6 GHz band. However more balanced DL/UL ratios could provide greater access to WAS/RLAN in the Upper 6 GHz band, but at the expense of reduced MFCN DL coverage/capacity due to fewer DL slots;
- Since MFCN frame transmission patterns impose specific limits on the minimum latency over the air, the WAS/RLAN use of MFCN UL timeslots would impose similar limits on the minimum latency delivered by WAS/RLAN. Such schemes would also intensify the interference from WAS/RLAN to MFCN during the UL slots.

Variable MFCN back-off might be an alternative approach, whereby upon detection of WAS/RLANs, MFCN would not transmit for a period of time to allow WAS/RLANs access to the channel. This is a similar approach to Listen Before Talk (LBT) in WAS/RLAN. However, MFCN are specified to access spectrum in a deterministic manner through scheduling algorithms. The introduction of such non-deterministic access mechanisms would not be aligned with the design of MFCN and could negatively impact their performance.

3.4.2.3 Geographical separation (including indoor/outdoor)

Geographical separation could occur at several levels:

- At building level (indoor/outdoor separation);
- At population density level (urban/rural separation);
- At local hotspot level, based on the connectivity requirement of identified buildings or lands (e.g. campuses).

For any such geographical separation mechanisms, interference may occur at the border between two zones with different priorities. There is an inherent trade-off between increasing the spectrum use (bringing the zones closer to each other) and managing the potential interference (moving the zones away from each other).

In particular, in the specific case of indoor/outdoor separation, some studies showed that it is not possible to perfectly isolate indoor from outdoor, see for example studies C2 and C3. However, some studies also showed that it is possible, under some assumptions, to derive indoor capacity benefits for WAS/RLAN and outdoor capacity benefits for MFCN in the same geographical area, see studies A1 (section 4.5), A2 (section 4.6), A3 (section 4.7), A4 (section 4.14), A5 (section 4.20), B2 (section 4.9), B3 (section 4.10), C7 (section 4.18).

3.4.3 Database-assisted awareness, decision and possible spectrum organisation

Database-assisted awareness mechanisms refer to technical solutions whereby a database, possibly operated by a third-party (commercially or on behalf of a national regulator) is automatically solicited by radio equipment in order to request transmission parameters, in response to information provided by the equipment within the query, (including, but not necessarily limited to the location of the requesting device). TV White Spaces (TVWS) devices, Automatic Frequency Coordination (AFC) for WAS/RLAN, and Citizen Broadband Radio Service (CBRS) for MFCN and WAS/RLAN are examples of implementations of such database-assisted techniques in other contexts.

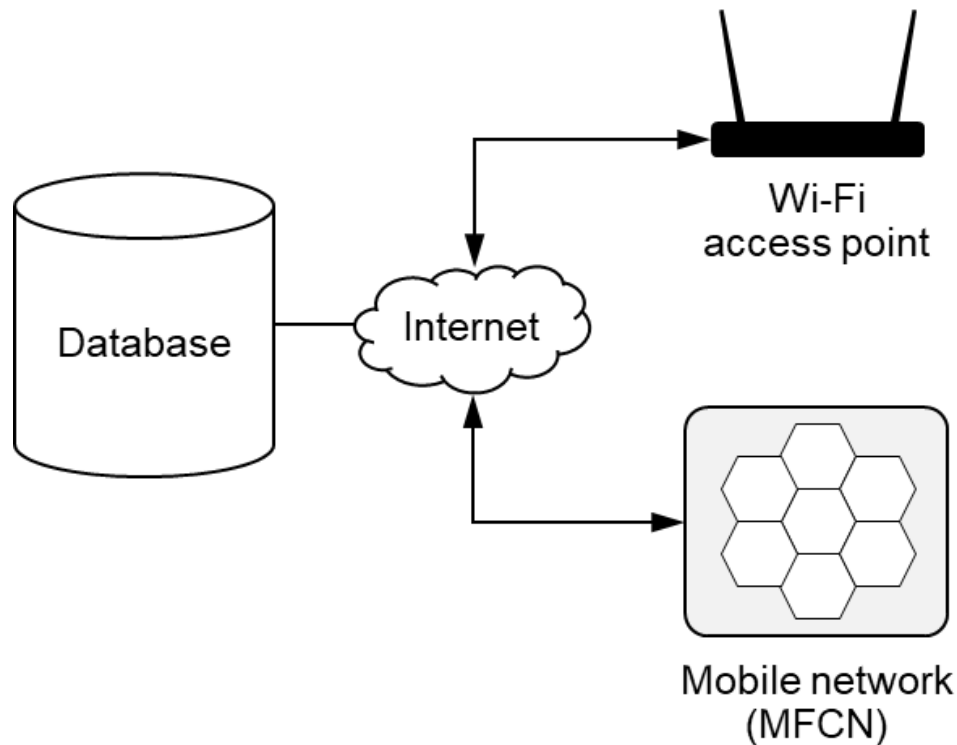


Figure 7: Database-assisted mechanisms

Database-assisted coordination mechanisms can be leveraged to facilitate separation between MFCN and WAS/RLANs in geographic location, time, or in frequency (band split). Such mechanisms can address the three aspects: awareness, decisions or prioritisation, and possible spectrum organisation. Note that databases might be updated as often as necessary, for example to allow some flexibility for changes over time in the extent of separation between MFCN and WAS/RLANs or their prioritisations.

Since such mechanisms rely on the requirements for MFCN and/or WAS/RLAN equipment to know their location and automatically and regularly query the relevant database, this requires the existence of a prior connectivity from the MFCN and/or WAS/RLAN APs to the database. MFCN UEs and WAS/RLAN STAs may not need to directly access the databases themselves and could be instead informed by MFCN BSs and WAS/RLAN APs, respectively.

The framework for the database-assisted mechanism, and in particular for the exchange of information between MFCN, WAS/RLAN APs, and the database, would need standardisation, harmonisation and compliance testing. Responsibility for operation, maintenance and update of such systems may also require harmonisation efforts.

The use of databases to implement separation in geographic location, time and frequency are further described below.

3.4.3.1 Database-assisted separation in geographic location

This potential sharing mechanism is based on the idea that – assisted by a geolocation database – MFCN and WAS/RLANs would avoid mutual co-channel interference in the Upper 6 GHz band by operating co-channel and at the same time subject to appropriate geographic separations.

Geographic separation between MFCN and WAS/RLANs can be implemented via a database. MFCN and WAS/RLAN APs would be required to automatically and regularly query a database and, having provided their respective geographic locations, would receive confirmation that they are authorised to access the Upper 6 GHz band at the said locations, and would be informed of any technical conditions which might apply.

Database-assisted separation in geographic location may allow MFCN and WAS/RLANs to operate co-channel and at the same time, affording flexibility to European regulators to tailor access to the Upper 6 GHz band in different ways according to their national policies. Such flexibility could be at the expense of cross-border coordination and buffer zones.

With regards to the performance of MFCN and WAS/RLANs, there would be no significant impact if the geographic separations between MFCN and WAS/RLANs are specified appropriately to avoid mutual interference. MFCN and WAS/RLANs would be able to deliver the best possible service at peak performance by using all the time/frequency resources available at the locations where the networks are authorised to operate. This is not the case for sharing through time division and frequency division.

Database-assisted geographic sharing would have little impact on the technical specifications of MFCN and WAS/RLAN radio technologies at the PHY and MAC layers as developed by the likes of 3GPP, IEEE and others. Nor would there be any required modifications, additional power consumption, or costs for the MFCN and WAS/RLAN radio equipment hardware, except for the capacity to geo-locate.

In addition to a harmonised framework for database-assisted separation in geographic location, and harmonised standards for the exchange of information, it would also be helpful if the calculations necessary for defining geographic restrictions (if not the protection criteria themselves) are also harmonised in order to simplify implementations by (or on behalf of) national administrations.

3.4.3.2 Database-assisted separation in time

This potential sharing mechanism is based on the idea that – assisted by a database – MFCN and WAS/RLANs would avoid co-channel interference by operating in the Upper 6 GHz band at mutually exclusive times. In the context of feasible coordination timeframes, separation in time is considered with a coarse granularity, whereby MFCN and WAS/RLANs would operate in mutually exclusive slices of time, where the duration of the slices is orders of magnitude greater than the duration of packets transmitted over-the-air.

To implement separation in time, the regulators would need to specify the time-division parameters (switching times and guard intervals) for the two radio system types. In the simplest implementation, the regulator could include the time-division parameters in the MFCN licenses and WAS/RLAN license-exemption regulations. But to allow flexibility in time division, and for a more robust compliance regime, the regulator could make the time-division parameter values available online in machine readable format – in what would effectively be a time-division database. MFCN and WAS/RLAN APs would then be required to automatically and regularly query the relevant time-division parameter values online.

The database-assisted mechanism outlined above could allow different time divisions for MFCN and WAS/RLANs in different geographic locations or over time – if so required – in response to changing demands. However, it is not clear whether any resulting benefits in more efficient use of spectrum would outweigh the involved performance costs, technological complexities, and the need for inter-regional and cross-border buffer zones and coordination.

With regards to impact on performance, MFCN and WAS/RLANs would only have access to a reduced portion of the time resource and would accordingly not be able to deliver the best possible service at peak performance. Moreover, regular interruptions in the operation of the MFCN and WAS/RLAN equipment would have implications on their performance, especially for delivery of latency-critical use cases. Furthermore, the radio protocols of the MFCN and WAS/RLAN equipment would need to regularly restart from scratch, resulting

in additional inefficiencies. For the above reasons, database-assisted time sharing would have a greater impact on the operation of MFCN and WAS/RLAN technologies' radio protocols as compared to database-assisted geographic sharing.

The implementation of time division would require substantial amendments to the MFCN and WAS/RLAN technical specifications at the PHY, MAC and radio resource management levels in order to address the regular interruptions to the operation of the networks. These amendments would need to be specified, standardised and harmonised. That said, such amendments would be less intrusive than those which would be required for separation in time with a fine granularity (where the duration of the slices is comparable with the duration of packets transmitted over-the-air).

3.4.3.3 Database-assisted separation in frequency

This potential sharing mechanism is based on the idea that – assisted by a database – MFCN and WAS/RLANs would avoid co-channel interference by each operating in a different portion of the Upper 6 GHz band, with mutual interference managed through frequency separation. Such a database mechanism would be required if the intention is to implement band partitioning which may vary with geographic location or over time.

The implementation of the mechanism itself can be relatively straightforward. The information on the applicable band partitioning would be made available online in machine readable format – in what would effectively be a band-partition database. MFCN and WAS/RLAN APs would then be required to automatically and regularly query the relevant information from the database.

The database-assisted mechanism described above could be used to allow different administrations to partition the Upper 6 GHz band in different ways in order to meet diverse national policies. This could be the foundation of a harmonised framework to allow country-specific partitioning. That said, this would inevitably introduce complexities in cross-border coordination and need for buffer zones along borders.

The database-assisted mechanism could also, in principle, allow different band partitioning in different geographic regions within a country (radio equipment would then also need to provide relevant information on their geographic location). The net benefits of such a scheme are questionable, considering the need for potentially large buffer zones between regions and the resulting geographic fragmentation and sterilisation. The mechanism could also allow national regulators to change an initial partitioning of the Upper 6 GHz over time, even potentially at short time scales (e.g. throughout the day). In practice, however, the redistribution of the available bandwidth among the licensed MFCN operators over short time scales would introduce costs/complexities.

Importantly, any changes to the band partitioning over time or in different geographic locations would impact the design radio equipment, which would then have to be able to cope with a large diversity of potential band-plans.

With regards to impact on performance, MFCN and WAS/RLAN would only have access to a reduced portion of the available frequency resource, and would accordingly not be able to deliver the best possible service at peak performance

The implementation of flexible frequency division would require some amendments to the MFCN and WAS/RLAN technical specifications. These amendments would need to be specified, standardised and harmonised.

3.5 ASSESSING THE SHARING APPROACHES (INCLUDING MECHANISMS)

Assessment of the overall technical benefits and drawbacks of sharing approaches and mechanisms studied in section 4 considers the following types of deployments:

- 1 Geographical areas of overlap where both WAS/RLAN and MFCN would be used;
- 2 Geographical areas where there is no overlap, or which are in proximity to areas of overlap, while recognising that uses may change over time which could lead to some overlap occurring.

Sharing approaches (including mechanisms if applicable) are assessed based on the following criteria:

- 3 Sharing performance: Performance from a network and user perspective of MFCN macro-cell coverage and capacity and spectrum access / throughput for WAS/RLAN;

In addition, the following information, where available, may also be provided to support the overall discussion on sharing approaches:

- 1 The estimated benefits and drawbacks (for MFCN and WAS/RLAN) implied by the proposed sharing solution, where appropriate, compared to the case without sharing
- 2 Implementation timescales due to the need to update MFCN and /or WAS/RLAN specifications/standards and any associated hardware and software changes, and the development of any associated conformity standards;
- 3 Complexity/cost for administrations, operators and users;

4 SUMMARY OF STUDIES

The following sections summarise the studies that have been undertaken. Studies consider interference mitigation mechanisms and quantify the degradations of service to victim systems and associated probabilities of potential interference with/without these mechanisms.

A list of the complete studies that are summarised in this section, is available [here](#).

4.1 STUDY C1 AND D4 DETECTABILITY OF MFCN DOWNLINK SIGNALS BY WAS/RLAN APS

4.1.1 Introduction

This site-general study examines the detectability of MFCN downlink signals by WAS/RLAN APs. Under standard conditions (i.e. no sharing mechanisms), WAS/RLAN APs are unable to consistently detect the MFCN downlink within a 300 m MFCN cell. Although not quantified in this study, not detecting the MFCN downlink could in some instances lead to interference. This study determines the detection probability using the WAS/RLAN energy detect threshold (EDT) and using the MFCN Synchronisation Signal Block (SSB).

4.1.2 Technical parameters

The antenna and power characteristics used for MFCN are those described in section 2.1 for urban macro deployments, apart from exceptions listed below. The WAS/RLAN parameters used are in line with section 2.2.1 with the exception of antenna gain which is assumed as a fixed value of 2.15 dBi.

The following MFCN parameters are assumed:

- MFCN *e.i.r.p.*: 73 dBm/100 MHz, 83 dBm/100 MHz for the SSB assessment (to ensure consistent detection of the MFCN SSBs).

The following WAS/RLAN parameters are assumed:

- EDT: -84 dBm/MHz (assuming $P_{\max} = 23$ dBm);
- Noise figure: 9 dB;
- Antenna height: according to ECC Report 316 [5]³;
- WAS/RLAN deployment: uniformly distributed in indoor locations throughout the cell.

The transmission losses are modelled according to the following options from Table 18:

- Propagation and clutter: Option 2, with the exception that Recommendation ITU-R P.452-17 [11] was used based on the available ITU-R implementation in line with Note 1 of Table 18;
- Clutter loss: Recommendation ITU-R P.2108 [12], extrapolation below 250 m. Results are provided when clutter loss is applied only to NLOS paths, as well as when it is applied to both LOS and NLOS;
- Line-of-Sight (LOS) probability from ETSI TR 138.901 Urban Macro (UMa) [13];
- Building entry loss: Option 1 (Recommendation ITU-R P.2109 [3]);
- Polarisation mismatch: Option 1 (0 dB).

The SSB assessment additionally uses the following parameters:

- Instead of using traffic beams for SSB transmission, a single broadcast beam is used, with horizontal and vertical 3 dB beamwidths of around 50 and 8 degrees, respectively, and a peak gain of 18.4 dBi;
- Table 19 contains the demodulation requirements for SSB decoding.

³ The WAS/RLAN height probabilities used in this study are the averages of columns >100k, >50k, and >25k in Table 18 [5].

Table 19: Demodulation requirements for SSB decoding [16]

Parameter	Receiver with 2 RX	Receiver with 4 RX
SNR (dB)	-5.3	-8.6

4.1.3 Study methodology

The sharing scenario considers a single MFCN sector with a single BS. In each snapshot of the Monte Carlo simulation, 3 UE are randomly located within the sector, uniformly distributed with 70% indoor and 30% outdoor. For the EDT case the BS is assumed to serve each UE (i.e. downlink/uplink coverage are assumed, although the latter is not addressed) and a beam points directly at it. For the SSB cases, beamforming dynamics towards the UEs are not considered, as this assessment assumes that SSB transmission occurs using a single broadcast beam.

10000 WAS/RLAN APs are deployed within the MFCN cell. The received power at each AP is calculated, taking into account various locations and conditions, including the MFCN BS beamforming patterns variability. Then, the received power at the APs is compared with either:

- a) an EDT level for WAS/RLAN systems operating in the 6 GHz band (ETSI EN 303 687 [7]) or
- b) the demodulation requirement level for SSB decoding in the technical Report ETSI TR 138 101-4, to determine the number of APs that can detect MFCN downlink signals.

All APs are considered to be located indoor with uniform distribution across floors and constant values of clutter and building entry loss.

4.1.4 Results and implications for WAS/RLAN and MFCN

Under standard conditions (i.e. no sharing mechanisms) and assuming BSs serve indoor/outdoor UEs WAS/RLAN APs are unable to detect the MFCN downlink based on EDT in about 70% of locations within the 300 m MFCN cell. These results are achieved using an EDT of -84 dBm/MHz for WAS/RLAN and applying Recommendation ITU-R P.2108 [12] clutter loss only to NLOS paths. If clutter loss is applied to both the LOS and NLOS paths, the WAS/RLAN APs are unable to detect the MFCN downlink in about 77% of locations.

When using the MFCN Synchronisation Signal Block (SSB) alongside an urban macro power level of 83 dBm/100 MHz, WAS/RLAN APs only fail to detect the MFCN downlink in fewer than 4% of locations. Note that the analysis in this study may be further improved, e.g. by optimising the MFCN BS SSB beam characteristics. Additionally, considering only a single BS reduces the chances of cell-edge APs to detect MFCN downlink signals, although this assumption is dependent on the SSB beam directions.

4.1.5 Discussion on benefit/drawbacks of studied sharing scenario

4.1.5.1 Impact for MFCN

The mitigation mechanism for Upper 6 GHz MFCN BSs remains transparent to their operation, allowing them to function normally with the transmission of SSB signals, which is essential for the mitigation process. Concerning performance impact on MFCN macro-cells such as throughput, spectral efficiency, and latency, there are no associated effects. Likewise, there are no impacts on coverage, service availability within the coverage area, hardware, software, environmental factors, complexity or costs for operators, costs for end users, time to market, standardisation requirements and timeline, regulatory harmonisation, or administrative complexities.

4.1.5.2 Impact for WAS/RLAN

WAS/RLAN equipment would be required to detect and decode SSB signals transmitted by MFCN BSs in the Upper 6 GHz channels, and upon successful detection, these devices must cease transmissions in those

channels. This requirement applies to both WAS/RLAN APs and STAs. Implementing this functionality would require hardware updates for signal detection capabilities. Software adjustments would also be needed to support the new protocols for signal detection and response. The additional task of periodically monitoring channels for pilot signals may lead to increased power consumption, affecting battery life, particularly for STAs. This could potentially result in higher costs for end users and might influence consumer adoption of WAS/RLAN technology. The timeline for implementing these changes would depend on IEEE specification updates and subsequent standardisation efforts at ETSI.

4.1.6 Conclusions

Based on this study, without mitigation measures, WAS/RLAN APs in 70% of locations fail to detect MFCN downlink signals within a 300 m cell.

Decoding of MFCN SSBs by WAS/RLAN equipment can increase the detection probabilities. The results of this study show, under an urban macro power level assumption of 83 dBm/100 MHz, the detection of MFCN SSBs could be an alternative to aid detection of MFCN presence by WAS/RLAN equipment.

4.1.7 Opportunities for further studies

In the future, exploring simulations of an entire MFCN network (e.g. 19 sites) instead of a single sector could offer additional insights. This approach may provide a broader view on network performance, interactions, and opportunities for optimisation. Additionally, an assessment of interference from WAS/RLAN APs that failed to detect MFCN downlink signals should be conducted to quantify the detection requirements depending on the acceptable level of interference, as well as possible mitigation strategies.

4.2 STUDY D1: CROSS-TECHNOLOGY SIGNALLING: DETECTION AND DECODING OF MFCN PILOT SIGNALS BY WAS/RLAN EQUIPMENT

4.2.1 Introduction

The proposed potential cross-technology signalling mechanism relies on the transmission of pilot signals by MFCN BSs, and the subsequent detection of the MFCN pilot signals by WAS/RLAN equipment. The study examines the use of existing pilot signals transmitted by 5G NR BSs in the form of the synchronisation signal blocks (SSBs) which play a fundamental role in the operation of 5G MFCN.

The results of the study show that the received MFCN SSB downlink signal power and SINR play an important role in determining the potential for WAS/RLAN equipment to detect the presence of MFCN and thereby, and upon successful detection, to vacate the channel.

4.2.2 Sharing scenario description

The sharing scenario considers a situation whereby indoor or outdoor WAS/RLAN equipment would monitor the transmissions from outdoor MFCN BSs in the Upper 6 GHz band. Upon the successful decoding of SSB pilot signals transmitted from the MFCN BSs in a given channel, the WAS/RLAN equipment would cease transmissions in the said channel.

4.2.3 Technical parameters

The study models MFCN downlink emissions from a total of 19 sites in a hexagonal arrangement with three MFCN BSs, or cells, per site (i.e. a total of 57 BSs), where each BS forms a broadcast beam randomly and with equal probability towards one of eight pre-defined directions within its cell. The inter-site distance is 450 metres and corresponds to an MFCN cell radius of 300 metres.

The study considers a MFCN BS *e.i.r.p.* of 81.6 dBm/80 MHz, and WAS/RLAN equipment with an antenna gain of 2.15 dBi. Both MFCN and WAS/RLAN are assumed to be operating co-channel in a channel bandwidth

of 80 MHz. The locations of WAS/RLAN equipment are assumed with a uniform random distribution within an MFCN cell, and at a height of 1.5 m above ground.

The SSB portion of the signal transmitted by the MFCN BS corresponds to a *e.i.r.p.* of 71.6 dBm.

Radio propagation from MFCN BSs to the WAS/RLAN equipment is modelled according to ETSI TR 138 901, section 7.4 [13], with low-loss (glass and concrete) and high-loss (infra-red reflecting glass and concrete) modelled with probabilities of 80% and 20%, respectively. This corresponds to a mean building entry loss of 20 dB.

4.2.4 Study methodology

The objective of the study is to model the statistics of the received MFCN SSB signal powers across the coverage area of macro-cellular MFCN BSs in dense urban areas in the Upper 6 GHz channel. In this way, it is possible to identify the likelihood that the received MFCN SSB downlink signals can trigger the evacuation of the WAS/RLAN equipment from the relevant channel in the band.

To this end, the study models the downlink emissions from a total of 57 MFCN BSs, where each BS forms a single SSB broadcast beam in its cell at any given time. The study then uses a Monte Carlo analysis to calculate the statistics of received SSB powers at different locations within the hexagonal area of a central MFCN cell by accounting for both the serving (wanted) SSB signal and inter-cell interference. Having calculated the wanted and unwanted SSB signal powers, the statistics of the SINR at WAS/RLAN equipment is then calculated at different locations in the central MFCN cell. The SSB receiver in the WAS/RLAN equipment is then assumed to correctly decode the received SSB signal if the SINR equals or exceeds the relevant thresholds specified by 3GPP.

4.2.5 Results and implications on WAS/RLAN and MFCN

It is shown that under the modelled scenarios, including a MFCN BS *e.i.r.p.* of 81.6 dBm/80 MHz, WAS/RLAN equipment is able to successfully decode the SSB pilot signals in virtually all outdoor locations, and in 98% to 99% of indoor locations within the coverage area of MFCN (i.e. within an MFCN cell). This is because the target SINR values of -5.3 and -8.6 dB (as specified by 3GPP) for the decoding of the SSB pilot signals is readily exceeded at the WAS/RLAN equipment in most locations given the assumed MFCN BS *e.i.r.p.*

In addition, it is demonstrated that the decoding of the SSB pilot signals by the WAS/RLAN equipment is far more robust than energy detection of the entire MFCN BS emissions (the latter having a success rate of 100% outdoors but only 75% indoors within an MFCN cell) as a means of identifying the presence of MFCN. This is because it is possible to decode an SSB pilot signal transmitted by an MFCN BS at much lower received signal powers (corresponding to target SINRs of -5.3 and -8.6 dB) than the EDT of WAS/RLANs (-85 dBm/80 MHz).

That said, the above are only indicative results based on statistical simulations. In practice, it is always possible that some WAS/RLAN equipment might be hidden from MFCN BSs due to obstructions and shadowing, to the extent that the equipment would not be able to detect the presence of the MFCN even through the decoding of MFCN pilot signals. Such WAS/RLAN equipment would continue to transmit and risk harmful interference to nearby MFCN UEs.

4.2.6 Conclusions

The study models the statistics of the wanted and unwanted (inter-cell interference) MFCN SSB signal powers as transmitted by MFCN BSs and received at WAS/RLAN equipment in a multi-cell MFCN environment, and then derives the statistics of the SSB SINR at the said receivers.

In the modelled scenarios, including a MFCN BS *e.i.r.p.* of 81.6 dBm/80 MHz, of which 71.6 dBm is dedicated to the transmission of SSBs, the study concludes that:

- a) WAS/RLAN equipment is able to successfully decode the transmitted SSB pilot signals in virtually all outdoor locations, and in 98% to 99% of indoor locations within an MFCN cell.

- b) the decoding of the SSB pilot signals by the WAS/RLAN equipment is far more robust than the use of energy detection (which has a success rate of 100% outdoors but only 75% indoors) as a means of identifying the presence of MFCN.

The proposed potential cross-technology signalling mechanism would apply to all WAS/RLAN equipment, including APs and STAs.

Finally, it should be noted that the proposed cross-technology signalling approaches based on transmission of 5G NR SSBs discussed here and the transmission of IEEE 802.11bc frames or public action frames discussed elsewhere in this Report, are all technology-specific mechanisms.

4.2.7 Opportunities for further studies

Further studies should account for various vendor-specific SSB beamforming mechanisms and the dynamic nature of the radio propagation channel, in order to better understand the efficacy of the mechanism in practice.

Further studies can investigate whether the efficacy of shared use of spectrum between MFCN and WAS/RLAN through the decoding of MFCN pilot signals could potentially be enhanced by combining this with the smartphone-assisted coordination mitigation mechanism, also proposed in this Report, whereby MFCN UEs would transmit “channel unavailable” WAS/RLAN signals outside the Upper 6 GHz band to trigger WAS/RLAN equipment to vacate the channel in the presence of MFCN.

4.3 STUDY D9: SIMULATION STUDY FOR CROSS-TECHNOLOGY SIGNALLING: DETECTION AND DECODING OF IEEE 802.11BC WAVEFORM TRANSMITTED BY MFCN BS AND UE BY WAS/RLAN EQUIPMENT AND MFCN PERFORMANCES WITH XTS

4.3.1 Introduction

The proposed spectrum sharing approach leverages transmission of IEEE 802.11bc signals by MFCN BS and UEs, referred to as cross-technology signalling (XTS), followed by the reception of the XTS by WAS/RLAN equipment. The main purpose of the cross-technology signalling is to allow WAS/RLAN equipment to detect the presence of MFCN and consequently appropriate action could be taken to mitigate interference.

The study compares the MFCN throughput under co-channel sharing regime with and without cross-technology signalling against the baseline MFCN throughput assuming no spectrum sharing (two technologies are deployed on different channels). It also evaluates the detection probabilities for WAS/RLAN devices of 802.11bc XTS for different power thresholds. The scenario simulated only evaluates the effectiveness of WAS/RLAN detect and vacate based on cross-technology signalling in reducing impact to MFCN throughput performance.

4.3.2 Study methodology

The sharing solution studied in this section is based on cross technology signalling (XTS) broadcasted by MFCN nodes - Base Stations (BS) and/or User Equipment (UE)– and received by WAS/RLAN nodes. The assumed action upon reception of IEEE 802.11bc XTS message is to vacate the channel (detect and vacate), other actions (e.g. power reduction from AP, etc.) which can be taken within the open loop approach were not analysed.

The impact of the choice of XTS received power threshold to vacate the channel on MFCN UL and DL and WAS/RLAN is studied. The impact of interference on MFCN UL and DL from WAS/RLAN active APs that have not vacated is also studied.

Correlated (co-located MFCN UEs and WAS/RLAN APs) and uncorrelated (random locations of WAS/RLAN APs with respect to MFCN UEs) coexistence scenarios have been studied. This refers to the relative location of instantaneously active WAS/RLAN APs and MFCN UEs. The motivation behind the choice is that in the case of overlapping deployments, the users experience a very different impact depending on their relative location compared to the aggressor node. Thus, the average performance in the time domain for co-located

users could largely differ from the UE performance averaged across all locations, and the average activity factor of WAS/RLANs is not sufficient to fully characterize the potential interference impact in this case. Hence, collocation corresponds to a worst case analysis as in practice WAS/RLANs do not transmit continuously and MFCN UEs do not receive continuously.

4.3.3 Technical parameters

MFCN parameters used in this contribution's results are aligned with the Annex 4.4 to Working Party 5D Chairman's Report Document 5D/716-E (June 2021) [20] whenever possible, with the exception of some of the cases specified here below:

- MFCN e.i.r.p.: 73 dBm/100 MHz;
- WAS/RLAN bands/channels: 100 MHz and 20 MHz when evaluating impact to MFCN DL UL respectively (same channel as MFCN UE);
- Only 1 Active UE per sector was considered;
- Free space path loss is assumed for the link between MFCN UE and WAS/RLAN AP when co-located with fixed 10 m separation, noting that this can be considered optimistic for indoor propagation (detection performances for UE-based XTS could be lower than the study concludes);
- For MFCN UL results, UE power control has been assumed with a channel bandwidth of 20 MHz. However, conducted power for MFCN UE XTS transmission is always max power (23 dBm/20 MHz); LBT at the WAS/RLAN AP is not considered;
- SINR threshold for decoding of XTS based on IEEE 802.11bc is set to 4 dB. This is a study choice, based on performance expectation derived from publicly available data from commercially available Wi-Fi AP devices in other bands;
- Two choices for transmission of XTS from BS are considered:
 - beamforming associated to data transmission, having high spatial selectivity;
 - beamforming associated to broadcast transmission.
- Two choices of location for WAS/RLAN AP and MFCN UEs are considered (APs are always located indoor):
 - "co-located" case: AP are always in near proximity of active UEs (10 m radius);
 - "random location": APs are randomly dropped within the cell.

4.3.4 Results and implications for WAS/RLAN and MFCN

The simulation results supporting the observations below refer to the scenario in which an open loop approach is considered for the cross-technology signalling. In particular, it is assumed that WAS/RLAN vacates the channel after detection/decoding of the XTS.

Table 20 summarises all the results in this section for clarity. All the results collected are for WAS/RLAN AP with omnidirectional RX/TX gain.

Table 20: XTS detection probability results for co-located and uncorrelated cases

Scenario Impact	XTS Config	XTS Power Threshold (dBm/20 MHz)	WAS/RLAN AP Detect and Vacate Probability		50%-tile MFCN throughput degradation		5%-tile MFNC throughput degradation	
			C (Note 1)	R (Note 1)	C (Note 1)	R (Note 1)	C (Note 1)	R (Note 1)
From WAS/RLAN to MFCN DL	Baseline (no XTS)	/	n.a. (Note 2)	n.a. (Note 2)	95%	<0.5%	n.a.	n.a.
	UE XTS	/	99%	12%	2%	2%	n.a.	n.a.
From WAS/RLAN to MFCN UL	Baseline (no XTS)	/	n.a. (Note 2)	n.a. (Note 2)	87 %	48%	ND, Tput=0	ND, Tput=0
	Broadcast beams	-82	67%	67%	8%	3%	25%	6%
	Broadcast beams	-62	27%	27%	34%	13%	87%	24%
	Data beams	-82	65%	36%	18%	18%	41%	30%
	Data beams	-62	35%	11%	30%	30%	47%	36%

Note 1: C = Co-located AP; R = Randomly located AP;
Note 2: XTS is not considered in this scenario, so detect and vacate probability results are not available

4.3.4.1 Technical impact to MFCN

From Table 20, it can be noted that if a BS *e.i.r.p.* is reduced with respect to the baseline value of 73 dBm/100 MHz used in this simulations, XTS transmission power would also be reduced thus a degradation can be expected in XTS detection and received signal strength performance. In turn, this is expected to have a stronger impact on the MFCN UL throughput, as the baseline UL performance does not depend on BS power, while WAS/RLAN impact due to missed XTS detection would increase.

The results show to be very sensitive to the relative location of APs with respect to active UEs. For the “co-location” case we always assume that AP are in near proximity of active UEs (10 m radius). In case of “random” deployment APs are randomly located within the cell. APs are always located indoor.

4.3.4.2 Technical impact for WAS/RLANs

The probability that a random AP successfully decodes XTS transmitted by the BS using broadcast beam above the 4 dB SINR threshold and with a received power larger than the power threshold of -82 dBm/20 MHz is 67% assuming fixed AP antenna gain and 56% assuming antenna gain according to the distribution in Table 12.

For transmissions based on BS with broadcast beam, there is negligible difference in XTS reception statistics when the AP is co-located with the MFCN UE, as should be expected. If the detect-and-vacate approach studied here is introduced, these probabilities reflect the percentages of APs that would vacate Upper 6 GHz and move to a different band.

4.3.5 Conclusions

IEEE 802.11bc based XTS can be leveraged to allow WAS/RLAN equipment to detect the presence of MFCN and – and with potential assistance from authorisation servers – to take appropriate action to avoid interference with MFCN. The system simulations results indicate that under considered assumptions, accounted for the expected activity factors of WAS/RLAN networks and assuming random locations across the MFCN cell area, the proposed procedure mechanism would allow WAS/RLAN APs to receive XTS transmitted by MFCN Base Stations with SNR > 4 dB in 56-67% of indoor locations, depending on both receiver and transmitter assumptions. A large range of degradation to MFCN UL throughput values can be observed, depending on XTS threshold, AP/UE location, up to 25% for -82 dBm/20MHz threshold and 87% for -62 dBm/20 MHz threshold at 5th percentile.

It is worth noting that if BS *e.i.r.p.* is reduced with respect to the baseline value of 73 dBm/100 MHz used in this simulations, XTS transmission power would also be reduced thus a degradation could be expect in XTS detection and received signal strength performances. In turn, MFCN UL throughput impact would be expected worse than the numbers included in this study, due to the larger number of APs that would not vacate the channel.

Further studies are needed to evaluate performance of MFCN and WAS/RLAN networks considering other device location models, accounting for mobility and varying traffic loads. Additionally, time domain aspects (e.g. impact of activity factor and time-frequency resources allocation) were not considered in this study. The impact of bursty interference from WAS/RLAN transmissions to MFCN procedures, in both the co-located and random AP location scenarios, should be studied in detail to inform the final assessment on the feasibility of the proposed spectrum sharing mechanism.

4.3.6 Opportunities for further studies

IEEE 802.11bc XTS detects interference conditions between MFCN BS and UE and WAS/RLAN access point. Suitable detection threshold should be investigated further so that adopted threshold does not lead to under or over protection of MFCN or WAS/RLAN deployments.

Further studies could be carried out also to assess the impact of coexistence in the co-located scenario taking into account time domain aspects (e.g. activity factor and time-frequency resources allocation).

4.4 STUDY D10: CROSS-TECHNOLOGY SIGNALLING: TRANSMISSION OF 3GPP SSB AND IEEE 802.11BC SIGNALLING BY MFCN BASE STATIONS, AND THEIR DECODING BY WAS/RLAN EQUIPMENT

4.4.1 Introduction

The proposed potential cross-technology signalling mitigation/sharing mechanism relies on the transmission of 3GPP 5G NR synchronisation signal block (SSB) or IEEE 802.11bc (uplink frame with higher layer payload) signalling by MFCN BSs, and the subsequent decoding of the signalling by WAS/RLAN equipment.

The results of the study show that the received downlink SINRs for the SSB and IEEE 802.11bc signalling play an important role in determining the potential for WAS/RLAN equipment to detect the presence of MFCN and thereby, and upon successful detection, to vacate the channel.

4.4.2 Sharing scenario description

The sharing scenario considers a situation whereby indoor WAS/RLAN equipment would monitor the transmissions from outdoor MFCN BSs in the Upper 6 GHz band. Upon the successful decoding of SSB or 802.11bc signalling transmitted from the MFCN BSs in a given channel, the WAS/RLAN equipment would cease transmissions in the said channel.

4.4.3 Technical parameters

The study models MFCN downlink emissions for the transmission of SSB or IEEE 802.11bc signalling from a total of 19 sites in a hexagonal arrangement with three MFCN BSs, or cells, per site (i.e. a total of 57 BSs), where each BS forms a broadcast beam randomly and with equal probability towards one of eight pre-defined directions within its cell. As part of a sensitivity analysis, IEEE 802.11bc signalling is also considered based on the use of traffic beams pointing towards MFCN UEs and their nearby WAS/RLAN equipment. The inter-site distance is 450 metres and corresponds to an MFCN cell radius of 300 metres.

The study considers MFCN BS *e.i.r.p.* levels of 81.6, 71.6, 66.6 and 55.6 dBm/80 MHz, and WAS/RLAN equipment with an antenna gain of 2.15 dBi and *e.i.r.p.* of 23 dBm/80 MHz. Both MFCN and WAS/RLAN are assumed to be operating co-channel in a channel bandwidth of 80 MHz.

The SSB and IEEE 802.11bc signals are assumed to be correctly decoded if the SINR at the receiver equals or exceeds a specified threshold. These thresholds are specified as -5.3 and -8.6 dB for SSBs (as specified by 3GPP), and 9 dB (as derived from the signal detection threshold specified by IEEE).

The locations of MFCN UEs and WAS/RLAN equipment are assumed to have a uniform random distribution within an MFCN cell and are assumed to be correlated. The WAS/RLAN interferer and MFCN UE receiver are both assumed to be at a height of 1.5 metres above ground, and with a horizontal separation of 0.5 to 10 metres.

Radio propagation from MFCN BSs to the UEs is modelled according to ETSI TR 138 901, section 7.4 [13], with low-loss (glass and concrete) and high-loss (infra-red reflecting glass and concrete) modelled with probabilities of 80% and 20%, respectively. Radio propagation from the WAS/RLAN equipment to the MFCN UE, corresponding to separations of 0.5 to 10 metres, is modelled as free space path loss.

4.4.4 Study methodology

The objective of the study is to model the statistics of the received SSB and IEEE 802.11bc signal powers across the coverage area of macro-cellular MFCN BSs in dense urban areas in the Upper 6 GHz channel. In this way, it is possible to identify the likelihood that the received SSB and IEEE 802.11bc downlink signals can trigger the evacuation of the WAS/RLAN equipment from the relevant channel in the band.

To this end, the study models the downlink emissions from a total of 57 MFCN BSs, where each BS forms a single SSB or IEEE 802.11bc broadcast beam in its cell at any given time along one of eight pre-defined candidate directions. The study then uses a Monte Carlo analysis to calculate the statistics of received SSB and IEEE 802.11bc powers at different locations within the hexagonal area of a central MFCN cell by accounting for both the serving SSB or IEEE 802.11bc signals, and inter-cell interference.

Having calculated the wanted and unwanted SSB or IEEE 802.11bc signal powers, the statistics of the SINR at WAS/RLAN equipment is then calculated at different locations in the central MFCN cell. The receiver in the WAS/RLAN equipment is then assumed to correctly decode the received SSB or IEEE 802.11bc signal if the SINR equals or exceeds the relevant thresholds specified by 3GPP and IEEE, respectively.

4.4.5 Results and implications on WAS/RLAN and MFCN

The modelling indicates that:

- 1 **SSB** – With a MFCN BS *e.i.r.p.* of 82 dBm/80 MHz, indoor WAS/RLAN equipment would be able to successfully decode the SSBs transmitted by MFCN BSs in 97% to 98% of indoor locations within an MFCN cell. With the MFCN BS *e.i.r.p.* reduced to 57 dBm/80 MHz, the corresponding proportion of locations reduces to around 65% to 75%. Notably, this last result also shows that a reduced MFCN BS *e.i.r.p.* of 57 dBm/80 MHz would still allow MFCN UEs to decode SSBs and synchronise/attach to MFCN in a majority of indoor locations.
- 2 **IEEE 802.11bc** – With a MFCN BS *e.i.r.p.* of 82 dBm/80 MHz, indoor WAS/RLAN equipment would be able to successfully decode the IEEE 802.11bc signals transmitted by MFCN BSs in around only 45% of

indoor locations within an MFCN cell. With the BS *e.i.r.p.* reduced to 57 dBm/80 MHz, the corresponding proportion of locations reduces to around 30%.

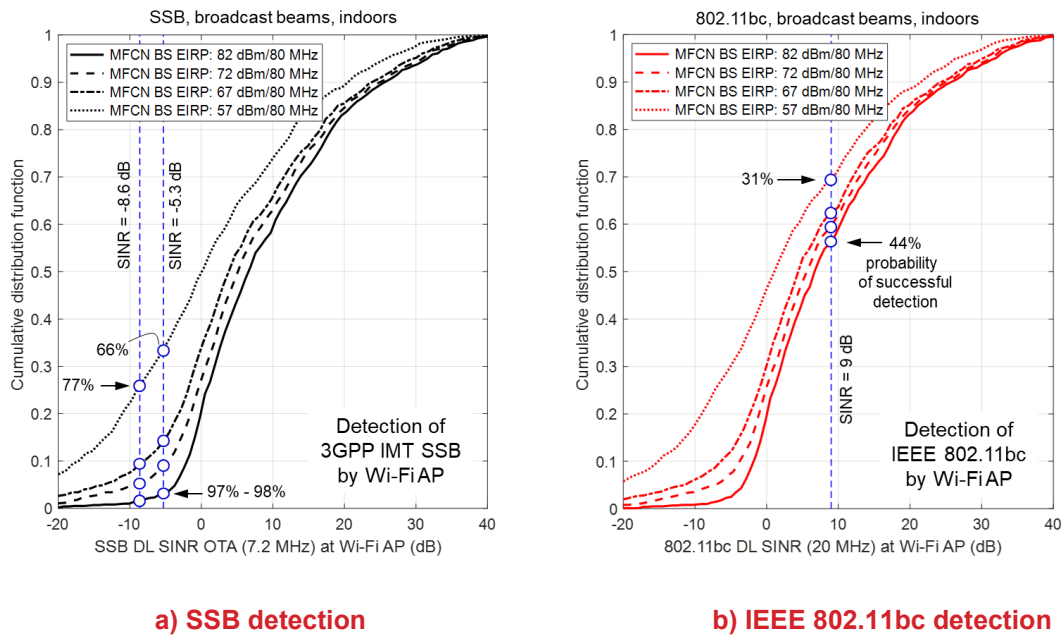


Figure 8: Statistics of SSB and IEEE 802.11bc (broadcast beams) indoor downlink SINR at a WAS/RLAN AP, for values of MFCN BS *e.i.r.p.* from 81.6 down to 56.6 dBm/80 MHz, and with target SINRs of $-5.3/-8.6$ dB for SSBs and 9 dB for IEEE 802.11bc

4.4.6 Sensitivity analysis

As a sensitivity analysis, the study also examines the case where the IEEE 802.11bc signals are transmitted by MFCN BSs via traffic beams (rather than broadcast beams), and furthermore quantifies the impact on the downlink SINR and throughput of MFCN UEs as a result of transmissions by nearby WAS/RLAN equipment which have failed to detect the presence of MFCN.

The modelling indicates that with a MFCN BS *e.i.r.p.* of 82 dBm/80 MHz, the emissions from indoor WAS/RLAN equipment which are subject to the IEEE 802.11bc cross-technology signalling mechanism would reduce the MFCN downlink throughput to zero in around 30% of indoor locations within the MFCN coverage area (i.e. an MFCN cell), up from 6% in the absence of WAS/RLANs.

Moreover, with the MFCN BS *e.i.r.p.* reduced to 57 dBm/80 MHz, the emissions from indoor WAS/RLAN equipment which are subject to the IEEE 802.11bc cross-technology signalling mechanism would reduce the MFCN downlink throughput to zero in around 55% of indoor locations within the MFCN coverage area (i.e. an MFCN cell), up from around 35% in the absence of WAS/RLANs.

4.4.7 Conclusions

The proposed potential mitigation mechanism relies on the transmission of 3GPP SSB or IEEE 802.11bc signalling by MFCN BSs, and the subsequent decoding of the signals by WAS/RLAN equipment. The study models the statistics of the wanted and unwanted (inter-cell interference) SSB and IEEE 802.11bc signal powers received at indoor WAS/RLAN equipment in a multi-cell MFCN environment, and then derives the statistics of the SSB and IEEE 802.11bc SINRs at the said receivers.

The study concludes the following:

- a) A sharing mechanism based on the decoding of SSBs by WAS/RLAN equipment would be more robust than a sharing mechanism based on the decoding of IEEE 802.11bc signals and would result in substantially greater probabilities of successful detection of MFCN. Specifically, for a MFCN BS *e.i.r.p.* of

81.6 dBm/80 MHz, SSB and IEEE 802.11bc signalling allow successful detection of MFCN in around 98% and 45% of indoor locations within an MFCN cell, respectively. This is because the former mechanism can achieve successful decoding at a much lower SINR.

- b) For a MFCN BS *e.i.r.p.* of 81.6 dBm/80 MHz, WAS/RLAN equipment would fail to decode the IEEE 802.11bc signals transmitted by MFCN BSs in a remarkably high proportion (45%) of locations within an MFCN cell, and this would lead to a non-negligible risk of interference from WAS/RLANs to MFCN.
- c) As might be expected, the performance of both the SSB and IEEE 802.11bc cross-technology signalling mechanisms degrades substantially with a reduction in the MFCN BS *e.i.r.p.*, as it becomes more challenging to detect the presence of MFCN, thereby jeopardising sharing. Specifically, for a MFCN BS *e.i.r.p.* of 57 dBm/80 MHz, SSB and IEEE 802.11bc signalling allow successful detection of MFCN in around 70% and 30% of indoor locations within an MFCN cell, respectively.

Furthermore, a sensitivity analysis indicates that for MFCN BS *e.i.r.p.* levels of 82 and 57 dBm/80 MHz, the emissions from indoor WAS/RLAN equipment which are subject to the IEEE 802.11bc cross-technology signalling mechanism via MFCN traffic beams would reduce the MFCN downlink throughput to zero in around 30% and 55% of indoor locations within an MFCN cell (up from 6% and 35% in the absence of WAS/RLANs), respectively.

The proposed potential mitigation mechanism would apply to all WAS/RLAN equipment which might result in harmful interference, including APs and STAs.

Finally, it should be noted that the proposed cross-technology signalling approaches based on transmission of 3GPP 5G NR SSB and IEEE 802.11bc signals discussed here and the transmission of IEEE public action frames discussed elsewhere in this Report, are all technology-specific mechanisms.

4.4.8 Opportunities for further studies

Further studies should account for various vendor-specific SSB and IEEE 802.11bc broadcast beamforming mechanisms and the dynamic nature of the radio propagation channel, in order to better understand the efficacy of the mechanisms in practice.

4.5 STUDY A1: MFCN AND WAS/RLAN SHARING

4.5.1 Introduction

This study considers the coexistence between MFCN and WAS/RLANs in the Upper 6 GHz band through Monte Carlo simulations. The studies considered sharing with separation distances, MFCN UE operating indoor/outdoor or outdoors only, various MFCN BS power levels, WAS/RLAN detecting and deferring to MFCN (e.g. with MFCN transmitting WAS/RLAN frame), and MFCN UE detecting WAS/RLAN (e.g. with WAS/RLAN transmitting MFCN frame) and choosing not to use the channel.

4.5.2 Technical parameters

System parameters followed Annex 4.4 from ITU-R Working Party 5D document 5D/716 [20] for the MFCN and ECC Report 302 [6] and ECC Report 316 [5] for WAS/RLANs. Deviations from these assumptions are outlined as follows:

- 1 MFCN base station transmit power of 4 dBm / 100 MHz / element (54.65 dBm *e.i.r.p.* / 100 MHz) was assumed in addition to the value from [20]: 22 dBm / 100 MHz / element (72.65 *e.i.r.p.* / 100 MHz);
- 2 MFCN UE deployment was assumed to be 0% indoor, 100% outdoor in addition to studying the impact assuming value in [20] of 70% indoor, 30% outdoor;
- 3 MFCN UE height was assumed to be 1.5 m for outdoor [20]); for indoor UEs, the WAS/RLAN device height distribution was used; WAS/RLAN bandwidth of 160 MHz (100%) was assumed;
- 4 polarisation loss of 3 dB was assumed;
- 5 separation distance was assumed as 35 meters from MFCN base station (baseline) with sensitivity studies assuming 50 meters outside of MFCN cell edge, or 300 meters from MFCN base station; and

- 6 locations of MFCN UEs and WAS/RLANs are assumed to have a uniform random distribution within an MFCN cell and are assumed to be uncorrelated.

4.5.3 Study methodology

The study employs Monte-Carlo simulations. In each simulation iteration, 3 UEs and 1 WAS/RLAN (with number of WAS/RLANs derived from Scenario A of Table 10), were placed randomly (and uncorrelated with respect to each other) within each base station sector and were assumed to be simultaneously transmitting (a single 3-sector MFCN deployment and a cluster of MFCN BSs were both considered). The SNR within a system, aggregate interference from all active interferers to the victim receivers, and the resulting SINR were computed for each simulation iteration, and the distribution of these metrics was presented for different sharing cases where MFCN BS, MFCN UE, and WAS/RLANs were all considered as interferers or victims.

4.5.4 Results and implications for WAS/RLAN and MFCN

The results of the study on the feasibility and impact of sharing are summarised in Table 21. The study concludes that a BS *e.i.r.p.* of 72.7 dBm/100 MHz results in more than 30% of WAS/RLAN devices experiencing an SINR degradation of more than 0 dB, which forces 12.5% of WAS/RLANs off the channel. No UEs that can connect to the BS suffer from a loss of connection (e.g. are not served) due to interference. These results suggest that base stations with an *e.i.r.p.* of 72.7 dBm/100 MHz do not share equitably with WAS/RLANs under these assumptions (i.e. WAS/RLANs would be impacted more than MFCN). However, with MFCN BS *e.i.r.p.* of 54.7 dBm/100 MHz, impact from interference is more equitable between indoor WAS/RLANs (3.5% not served) and outdoor UEs (6.7% not served). The UEs not covered are near the edge of the cell, where uplink performance is typically worse anyway; near the base station, sufficient SNR on the uplink and downlink was achieved.

Table 21: Percent of WAS/RLANs UEs impacted in sharing studies

	Device Condition	1 Base station Outdoor UEs only		7 Base stations Indoor/Outdoor UEs		
	Base station Power (dBm/100 MHz)	72.7	54.7	54.7		
WAS/RLAN Impact	SINR at WAS/RLAN < SNR _{min}	9.9%	2.4%	1.0%		
	SINR at WAS/RLAN < SNR _{min} or interference from MFCN system at WAS/RLAN ≥ -85 dBm/MHz	10.3% (Note 1)	2.6%	N/A		
	SINR at WAS/RLAN < SNR _{min} or interference from MFCN at WAS/RLAN ≥ -95 dBm/MHz	12.5%	3.5%	3.5%		
MFCN Impact	MFCN UE Location	Outdoor	Outdoor	Outdoor	Indoor	Indoor+Outdoor
	SINR at UE < SNR _{min} or interference from WAS/RLAN at UE ≥ -95 dBm/MHz (for 7 Base stations only)	0.29%	19.4%	6.67%	61.66%	45.13% (Note 2)
	SINR at BS < SNR _{min}	11.0%	10.9%	0.00%	28.12%	19.67%
	SNR _{atUE} < SNR _{min} while SNR _{atBS} > SNR _{min}	0.0%	8.4%	6.67%	33.54%	25.46%
Note 1: 4.4% of WAS/RLANs locations detect MFCN using EDT and 5.9% of WAS/RLANs are degraded below their minimum SNR requirements, result in a combined 10.3% of WAS/RLANs being unable to operate. Note 2: 0.18% of MFCN UE defers if power at or above -95 dBm/MHz (e.g. MFCN UE detects an WAS/RLAN frame). This value is 0.16% for the case of single MFCN BS.						

The baseline study considered a minimum 35 m separation distance (results in Table 21 include this separation) from an outdoor base station to an indoor WAS/RLAN. In addition, the impact of a greater spatial separation between the MFCN base station and WAS/RLANs was explored. A 300 m separation radius and a 50 m separation from the edge of the cell were both considered and both resulted in a ~15 dB interference reduction at both MFCN BS/UEs and WAS/RLANs, with respect to a case without separation distances enforced.

4.5.5 Discussion on benefit/drawbacks of studied sharing scenario

Performance impact on MFCN macro-cells and/or WAS/RLANs is minimal under the study assumptions when the MFCN BS *e.i.r.p.* was 54.7 dBm/100 MHz and MFCN seeks only to serve outdoor UEs. Only 3.5% of WAS/RLANs were forced off channel and 6.7% of outdoor MFCN UEs that could connect to the BS did not meet the minimum downlink SNR. Both MFCN and WAS/RLAN systems can operate in dense urban areas.

It can be noted that nearly all end user equipment with an MFCN radio has a WAS/RLAN radio and has the ability to transmit over multiple MFCN bands. This means that in the event of inadequate 6 GHz MFCN coverage, the UE may roam to another MFCN band or may roam to WAS/RLAN.

4.5.6 Conclusions

When MFCN and WAS/RLAN systems are separated spatially (indoor WAS/RLAN/outdoor MFCN BS and UE and/or creating separation distances between the two networks), with uncorrelated locations, this study indicated that MFCN BS operating at 73 dBm/100 MHz *e.i.r.p.* does not share equitably with WAS/RLAN. With indoor/outdoor separation considering a single base station, 12.5% of the WAS/RLANs either vacated the channel (when detecting MFCN signal at ≥ -95 dBm/MHz) or were unable to operate with the minimum SNR requirements. Furthermore, the I/N at 10% exceedance probability (i.e. CDF) was reduced by ~20 dB when 300 m separation distance or 50 m from the BS cell edge was imposed. However, under all above scenarios there was no negative impact to the percentage of MFCN UEs that were able to connect to the BS.

In the case of a reduced-power MFCN BS (approximately 55 dBm/100 MHz *e.i.r.p.*), for a single MFCN base station, the percentage of indoor WAS/RLANs that could not connect or had to vacate the channel was reduced to 3.5%. The percentage of outdoor MFCN UEs that were unable to connect while meeting MFCN BS downlink minimum SNR requirement was 8.4%. Considering a deployment of seven MFCN base stations, the above percentages were 3.5% for WAS/RLANs and 6.7% for outdoor MFCN UEs. While the reduced power decreases the downlink MFCN base station coverage for outdoor UEs, simulations show that the downlink coverage remains consistent with uplink coverage. The study shows that a larger percentage of WAS/RLANs are affected when WAS/RLANs defer to MFCN at ≥ -85 dBm/MHz (energy detection) or ≥ -95 dBm/MHz (WAS/RLAN frame detection) because they vacate the channel, but the SINR degradation is less. The same holds true for MFCN when it detects a WAS/RLAN signal. Finally, when separation distances of 300 m from BS or 50 metres from BS cell edge are imposed, the I/N at 10% exceedance probability (i.e. CDF) was reduced by ~20 dB for both systems.

4.5.7 Opportunities for further study

Future studies could investigate the impact on data throughput, latency, and reliability for each system. Furthermore, the impact of intra-network interference with respect to the MFCN network could be considered.

4.6 STUDY A2: INTERFERENCE ASSESSMENT BETWEEN MFCN HIGH POWER OUTDOOR AND WAS/RLAN INDOOR

4.6.1 Introduction

The study considers a scenario with MFCN 6 GHz BS deployed over the existing outdoor 3.5 GHz sites in Paris and WAS/RLAN LPI deployed indoor.

The goal of the study is to provide a high-level assessment of the dominant interference mechanisms for the sharing scenario aiming at indoor WAS/RLAN and outdoor-only MFCN.

4.6.2 Technical parameters

All relevant existing MFCN 3.5 GHz sites in the simulation area are considered, leading to a much denser MFCN deployment than the assumptions in section 2. The study considers a single sector per BS and does not consider beamforming. The study considers 68 dBm/5 MHz *e.i.r.p.* for all BS, 23 dBm *e.i.r.p.* for all MFCN UEs.

The study considers WAS/RLANs and MFCN UEs in very close proximity, corresponding to a very rare occurrence given the deployment density assumptions.

The study does not consider timing (frame, activity factor, network load) aspects but provides a higher bound on interference.

The propagation model is Winner II [10] combined with a Recommendation ITU-R P.2109 [3] for the building entry loss corresponding to 30% thermal efficient buildings, 70% traditional buildings.

4.6.3 Study methodology

The study first estimates the average propagation loss, then performs a sensitivity analysis on the propagation characteristics. The sensitivity analysis combines the 10% highest pathloss with the 10% highest building entry loss to determine the 1% lowest interference. Similarly, the sensitivity analysis combines the 10% lowest pathloss with the 10% lowest building entry loss to determine the 99% highest interference.

The study considers all devices transmitting at *e.i.r.p.* in the direction of the interfered device.

4.6.4 Results and implications for WAS/RLAN and MFCN

4.6.4.1 Considerations on location

- Locations of overlap where both WAS/RLAN and MFCN would be deployed: urban areas, with MFCN deployed outdoor and WAS/RLAN deployed indoor;
- Locations where only MFCN would be deployed: outdoor;
- Locations where only WAS/RLAN would be deployed: not considered in this study, as the scenario leads to high MFCN DL received signal indoor.

4.6.4.2 Main results

The mean outdoor MFCN best server in the DL is found to be at -21 dBm, corresponding to a mean pathloss of 101 dB over a 1 km x 1 km geographical area in the centre of Paris. This leads to a mean indoor aggregate interference from MFCN BS to WAS/RLAN of -37.5 dBm. The 1% (respectively 50 and 99%) noise increase due to interference from the MFCN BS to the WAS/RLAN is 34 dB (respectively 51.5 and 70 dB).

From the WAS/RLAN AP to the MFCN BS, the mean pathloss is found to be 122.5 dB, leading to a desensitisation of the MFCN BS by 7.5 dB. The 1% (respectively 50 and 99%) I/N due to interference from the WAS/RLAN to the MFCN BS is -12 dB (respectively 7.5 and 29 dB).

WAS/RLAN AP and MFCN UE in close proximity (on either side of a building wall) both create a mean interfering signal of -37 dBm towards each other, corresponding to significant interference. The 1% SINR at WAS/RLAN AP (respectively 5G UE) is 37 dB (respectively 40 dB) while the 99% SINR is -16 dB (respectively 0.5 dB).

4.6.5 Conclusions

The study suggests that high power MFCN outdoor cannot share the spectrum with WAS/RLAN indoor. The main interference mechanism is the interference from the MFCN BS to the WAS/RLAN, although there is also interference from the WAS/RLAN to the MFCN BS for WAS/RLAN in close proximity to the BS.

Interference from outdoor MFCN UE to indoor WAS/RLAN (as well as the opposite) are closely related to the positioning of the devices and the activity factors. Such interference mechanisms seem to be less problematic, due in particular to the mobility of the equipment considered.

Further studies may clarify whether specific mechanisms are required to ensure that indoor MFCN UEs do not connect to outdoor MFCN BSs in this frequency band.

Further studies may also be required to identify potential mitigation mechanisms, in particular for the dominant interference scenarios.

4.6.6 Opportunities for further studies

Further studies could consider lower MFCN BS *e.i.r.p.*, the impact of AAS antennas and the impact of the activity factor.

4.7 STUDY A3: SHARING BETWEEN MFCN AND INDOOR WAS/RLAN IN URBAN ENVIRONMENT

4.7.1 Introduction

This study investigated the sharing of spectrum between MFCN and indoor WAS/RLAN in urban environments, with an assumption that Upper 6 GHz MFCN is focussed on providing service outdoors while WAS/RLAN and 3.4-3.8 GHz MFCN are focussed on providing service indoors. It explores the effect of different MFCN macro base station powers on the way users could be served across the 3.4-3.8 GHz and Upper 6 GHz bands, considering both geographically even and hotspot user distribution. The study quantifies the access to the band by WAS/RLAN and MFCN. It also quantifies MFCN interference at WAS/RLAN APs and WAS/RLAN AP interference at Upper 6 GHz BSs and UEs, with and without a sharing mechanism.

4.7.2 Technical parameters

Selected parameters in line with those in section 2 of this Report:

- MFCN bands/channels considered: indoor and outdoor UEs distributed across 3.4-3.8 GHz and 6.425 - 7.125 GHz;
- WAS/RLAN bands/channels considered: indoor APs distributed across 5 GHz, Lower 6 GHz and Upper 6 GHz channels;
- MFCN BS *e.i.r.p.* levels: various levels were modelled between 53 and 73 dBm/100 MHz;
- Urban environment with MFCN application delivered from the same macro-cell network grid with density of 10 BSs/km² (inter-site distance of 590 m, hexagon long diagonal of 390 m); Aligned with Doc 5D/716 [20], specifying for 3.4-3.8 GHz “10 BSs/km² urban” and a “0.4 km urban” cell size. This Report and Doc 5D/716 [20] also define a 300 m MFCN cell size for 6 GHz urban macro-cells. A density of 10 BS/km² with a 400 m MFCN cell size ensures contiguous coverage, whereas with a 300 m MFCN cell size results in non-contiguous coverage covering about 60% of the simulation area;
- Co-channel interference calculation: impact of BSs on APs, and of APs on BSs and UEs, was calculated for different 6 GHz BS power levels;
- MFCN loading factor: the study modelled both 20% and 50% network loading factors;
- SINR to spectral efficiency mapping: SISO curve as provided in this Report;
- Propagation model: Recommendation ITU-R P.1411-12 [9], LOS from 3GPP TR 38.901 UMa [13], BEL from Recommendation ITU-R P.2109-2 [3];

- Simulation area: 21 hexagons with a long diagonal of 390 m, as a result of a density of 10 BS/km².

Extended Parameters:

- Reference Signal Received Power (RSRP) level for handover and admission to the band: –105 dBm/ 30 kHz and –115 dBm/ 30 kHz (sensitivity);
- Locations of MFCN UEs and WAS/RLAN equipment are assumed to have a uniform random distribution within the simulation area and are assumed to be uncorrelated;
- Indoor-to-outdoor ratio of simulated UEs: 70:30 (baseline) and 34:66 (sensitivity case);
- Simulation area – Sensitivity: 21 hexagons, long diagonal of 300 m corresponding to density of 17 BS/km².

Extended Methods:

- UE split between 3.4-3.8 GHz and Upper 6 GHz: method to calculate traffic bitrate and UE split to achieve 20% or 50% loading, equal throughput per UE in each band (allowing for different throughput between bands) and maximum network throughput. Sensitivity case with equal throughput per UE regardless of the band;
- Sharing mechanism: 6 GHz BSs transmit IEEE 802.11bc uplink frames on traffic beams (not broadcast beams), and these are assumed to be decoded successfully if the received power level is above the WAS/RLAN signal detection threshold.

4.7.3 Study methodology

The methodology is based on the following steps:

- UE split between 3.4-3.8 GHz and Upper 6 GHz. As the two MFCN bands have unequal transmit power, antenna patterns and propagation losses, each band is assigned the appropriate UEs;
- Co-channel interference was calculated at WAS/RLAN APs to quantify the impact of MFCN BSs and UEs;
- Co-channel interference was calculated at MFCN BSs and UEs to quantify the impact of WAS/RLAN APs;
- Variation of the MFCN power level and repetition of the steps above;
- Sensitivity cases: indoor-to-outdoor ratio (34:66) suitable for dense urban, with equal throughput per UE across both bands, without a sharing mechanism, higher MFCN network density associated with dense urban (17 BS/km²), and with RSRP threshold for handover/admission of –115 dBm/30 kHz.

4.7.4 Results and implications for WAS/RLAN and MFCN

4.7.4.1 Sharing summary

Referring to the baseline simulation area (10 BSs/km², hexagon long diagonal 390 m), study results show WAS/RLAN operation in indoor locations is facilitated when MFCN BS *e.i.r.p.* at Upper 6 GHz is 57 dBm/100 MHz, with APs at 80% of indoor locations able to access the band. At the same time, MFCN access to the Upper 6 GHz band is possible from around 73% of outdoor locations, with little interference between the two technologies, suggesting that – in the context of band access without undue interference – there could be overall benefits to sharing compared to use of the band by one technology alone. Notably, the MFCN band access exceeds the 60% coverage which corresponds to a 300 m MFCN cell size in comparison to a cell with a long diagonal of 390 m.

- MFCN band access and throughput:
 - With an MFCN BS *e.i.r.p.* of 57 dBm/100 MHz and a –105 dBm/30 kHz admission threshold, UEs can access the 6 GHz band in 73% of outdoor locations. In a dense urban sensitivity scenario (with 34% of UEs located indoors), UEs can access the band in 90% of outdoor locations. With RSRP threshold for handover/admission closer to the coverage limit (–115 dBm/30 kHz), UEs can access the band in 98% of outdoor locations. The results also show that MFCN mean throughput is doubled compared to 3.4-3.8 GHz alone.
- WAS/RLAN band access:

- At MFCN *e.i.r.p.* of 57 dBm/100 MHz, APs at around 80% of indoor locations can access the Upper 6 GHz, with the remainder receiving IEEE 802.11bc uplink frames from 6 GHz BSs above the Signal Detection Threshold, which is assumed to block their access. APs at around 80% of indoor locations can access the Upper 6 GHz if MFCN BS density is higher at 17 BS/km² (450 m inter site distance), and if the APs are assumed in thermally-efficient buildings. At 73 dBm/100 MHz MFCN BS *e.i.r.p.*, WAS/RLAN access falls to about 35% of indoor locations, and with an assumption of equal throughput per UE across both bands, it drops further to 25%;
- Interference at Upper 6 GHz WAS/RLAN:
 - With an MFCN BS *e.i.r.p.* at 57 dBm/100 MHz, the I/N threshold due to interference from BSs at the APs is exceeded in only 2% of indoor locations in the Upper 6 GHz, corresponding to the percentage of AP locations experiencing a 5% throughput loss;
- Interference at 6 GHz MFCN:
 - At MFCN BS *e.i.r.p.* of 57 dBm/100 MHz and 50% network loading, the I/N target is exceeded in only 2% of uplink locations and 1% of downlink locations.

4.7.4.2 MFCN coverage

At 6 GHz and with MFCN BS *e.i.r.p.* of 57 dBm/100 MHz, a link-budget analysis indicated that non-zero downlink throughput (SINR \geq -10 dB) can be achieved with 95% confidence in outdoor locations within 410-490 m, depending on the shadow fading margin assumption. Fewer UEs could access the band in the first place though due to a more stringent RSRP criterion for admission.

4.7.4.3 MFCN capacity benefits from Upper 6 GHz

- Baseline scenario – The study results indicate that with 3.4-3.8 and Upper 6 GHz networks having equal bandwidth, even with an Upper 6 GHz MFCN BS *e.i.r.p.* of 57 dBm/100 MHz, the combined mean throughput over the 390 m MFCN cell is about double that of the 3.4-3.8 GHz alone. This capacity boost is because the 6 GHz network serves more outdoor users, as its power level limits indoor reach. This offloads the outdoor users from 3.4-3.8 GHz, leaving that network to handle predominantly indoor users. Higher 6 GHz *e.i.r.p.* primarily benefits service indoors in that band;
- Different indoor-to-outdoor ratio assumption – The uplift in MFCN capacity by combined use of 3.4-3.8 GHz and Upper 6 GHz is in the same order if the outdoor demand were to be considered a larger proportion of the total demand (indoor-to-outdoor ratio 34:66 as calculated for dense urban, instead of 70:30);
- Uniform demand / Equal throughput per UE across both bands – If UEs achieve the same throughput regardless of network connection and location, an MFCN *e.i.r.p.* of 57 dBm/100 MHz delivers a 66% increase in mean throughput compared to 3.4-3.8 GHz alone, with a 35% loading factor on the Upper 6 GHz band, indicating available spare capacity.

4.7.5 Conclusions

The study concludes that spectrum sharing in the Upper 6 GHz band (based on handovers steering more indoor MFCN traffic to 3.4-3.8 GHz and more outdoor traffic to 6 GHz, and with sharing mechanism of 6 GHz BSs transmitting IEEE 802.11bc uplink frames on traffic beams) appears possible – with high levels of indoor WAS/RLAN availability (80% of locations) and high levels of outdoor MFCN UE availability (at least 73% of locations) – when delivered from macro-cell density of 10 BS/km² (inter-site distance of 590 m, hexagon long diagonal of 390 m) and using an MFCN *e.i.r.p.* of 57 dBm/100 MHz. This power level seems well suited for serving outdoor users in the Upper 6 GHz band. This is because firstly, non-zero MFCN throughput (SINR \geq -10 dB) is provided in 95% of locations within 410-490 m exceeding the hexagon long diagonal, and band access (RSRP \geq -105 dBm/30 kHz) in at least 73% of outdoor locations. Secondly, similar outdoor capacity can be achieved with an *e.i.r.p.* of between 57 and 65 dBm/100 MHz, higher power levels increasing the risk of interference to indoor WAS/RLAN but with little benefit for increasing the mean throughput of the MFCN network outdoors suggesting 57dBm/100 MHz *e.i.r.p.* could be appropriate. Power levels of 73 dBm/100 MHz *e.i.r.p.*, while beneficial for indoor MFCN applications, restrict significantly WAS/RLAN access to the band, particularly in traditional-built buildings.

4.8 STUDY B1: FOCUS GEOGRAPHICAL AREAS FOR SHARING

4.8.1 Introduction

This study investigates the geographical areas of interest for shared use of the Upper 6 GHz band. The areas with high population density correspond to the priority deployment areas for both MFCN and WAS/RLAN.

4.8.2 Technical parameters

The study does not deviate from the assumptions in section 2.

4.8.3 Study methodology

The study lists geographical areas with population density above 8000 (respectively 15000) habitants per square kilometre. These reference population densities were extracted from socio-economic studies [30], [31] supporting the demand for opening the 6425-7125 MHz band to MFCN.

4.8.4 Results and implications for WAS/RLAN and MFCN

4.8.4.1 Considerations on location

- Locations of overlap where both WAS/RLAN and MFCN would be deployed: both WAS/RLANs (see SE45 deployment model) and MFCN expect that their spectrum demand is correlated with the population density;
- Locations where only MFCN would be deployed: not applicable to this study;
- Locations where only WAS/RLAN would be deployed: not applicable to this study.

4.8.4.2 Main results

At EU level, 9 cities have a population density above 15000 habitants per km², corresponding to 1% of the EU population and cover 0.007% of the EU geographical area. 22 cities have a population density above 8000 habitants per km², corresponding to 2.2% of the EU population and extend on 0.02% of the EU geographical area.

A more detailed analysis was conducted for the specific case of Germany. The neighbourhoods of German cities exceeding 15000 habitants per km² cover 0.4% of the geographical area of these cities and less than 2% of their population. The same areas correspond to 0.003% of the German territory and 0.2% of the population. The neighbourhoods of German cities exceeding 8000 habitants per km² cover 5% of the geographical area of these cities and 18% of their population. The same areas correspond to 0.05% of the German territory and 2.3% of the population.

4.8.5 Conclusions

The study indicates that the geographical areas in Europe required to meet the GSMA's estimated mid-band spectrum needs for the foreseeable future (until 2030) account for less than 2.2% of the EU population and 0.02% of the EU's geographical area. While this may present opportunities for geographical sharing, it is important to note that the demand for both MFCN and WAS/RLANs is proportional to population density, making their geographical requirements perfectly correlated.

While previous studies focused on opening the 6425-7125 MHz band exclusively to WAS/RLAN or MFCN the shared use of the band is likely to combine the benefits of opening the band to either technology:

- MFCN networks would be in a position to increase their capacity where required, while delaying network densification;
- WAS/RLAN devices would get access to additional channels, not only in rural areas, but also partially in dense urban areas.

Shared use of the Upper 6 GHz band could prioritise outdoor coverage by MFCN and indoor coverage by WAS/RLAN, reducing the need for MFCN (respectively WAS/RLAN) to compensate Building Entry Loss (respectively Building Exit Loss) through higher transmit power.

4.8.6 Opportunities for further studies

Further studies would be required in individual CEPT countries to determine the geographical areas relevant for shared use of the 6 GHz band in each country.

4.9 STUDY B2: MEDIUM POWER OUTDOOR MFCN AND INDOOR WAS/RLAN IN FRANKFURT

4.9.1 Introduction

The study provides a detailed assessment of the sharing scenario aiming at indoor WAS/RLAN and outdoor-only MFCN.

4.9.2 Technical parameters

The study considers one MFCN sector corresponding to an existing 3.5 GHz site in Frankfurt leveraging the topography of actual buildings. MFCN inter-cell interference is not modelled. While the topography is a specific site in Frankfurt, a sensitivity analysis is performed on the population density.

The study assumes WAS/RLAN LPI and MFCN UEs transmitting at maximum *e.i.r.p.* in the direction of the interfered device. The MFCN BS *e.i.r.p.* considers both 68 dBm/80 MHz and reduced *e.i.r.p.* levels.

The study assumes that MFCN and WAS/RLAN both operate over 80 MHz channel, fully co-channel. The MFCN base station is leveraging an AAS antenna and serving three users in the cell. Both WAS/RLANs and MFCN UEs are deployed at ground level.

Locations of MFCN UEs and WAS/RLAN equipment are assumed to have a uniform random distribution within respectively indoor (WAS/RLANs) and outdoor (MFCN UEs) locations of an MFCN cell and are assumed to be uncorrelated. The timing aspects, including the MFCN TDD factor and cell load as well as the activity factor of WAS/RLANs, are not taken into account in this study.

The propagation model is Recommendation ITU-R P.452 [11] with clutter loss according to Recommendation ITU-R P.2108-1 [12].

4.9.3 Study Methodology

The study is based on a Monte Carlo analysis. For each instance, the SINR is derived for the MFCN BS as well as in each indoor location (WAS/RLAN SINR) and outdoor location (MFCN UE SINR).

The metric considered is the degradation of SINR, i.e. the difference in SINR between a network without interference and a network with interference.

The study performs a Monte Carlo analysis in the spatial domain, but does not take into account the timing domain, and factors such as MFCN frame format, WAS/RLAN channel access mechanisms, MFCN cell load, MFCN and WAS/RLAN activity factors, channel adaptation and retransmission mechanisms. The simulation also assumes that a WAS/RLAN AP receiving the MFCN DL signal above the EDT would vacate the channel.

4.9.4 Results and implications for WAS/RLAN and MFCN

4.9.4.1 Considerations on location

- Locations of overlap where both WAS/RLAN and MFCN would be deployed: in urban areas, MFCN would aim at outdoor coverage while WAS/RLAN LPI would aim at indoor connectivity;

- Locations where only MFCN would be deployed: not considered in this study;
- Locations where only WAS/RLAN would be deployed: not considered in this study.

4.9.4.2 Main results

A reduction of the MFCN DL signal by 15 dB (respectively 20 dB) from on an MFCN BS *e.i.r.p.* of 68 dBm/80 MHz enables WAS/RLAN operation indoor with SINR degradation limited to less than 10 dB (respectively 5 dB), assuming a 100% MFCN network loading. The median SINR at outdoor MFCN UE is reduced, it is degraded by 15 dB (respectively 20 dB) compared with the MFCN coverage in absence of interference and MFCN *e.i.r.p.* of 68 dBm/80 MHz, assuming that WAS/RLAN transmits with a 100% activity factor.

However, when reducing the MFCN DL signal by 15 dB, the WAS/RLANs EDT is no longer triggered and indoor WAS/RLANs in close proximity of the MFCN BS stay on the channel, leading to a reduction of 5 dB or less in median SINR at the MFCN BS for very high population density, assuming that WAS/RLAN transmits with a 100% activity factor.

A mechanism allowing WAS/RLAN in close proximity to the MFCN BS to detect it would prevent interference from WAS/RLAN to the MFCN BS. A reduction of the EDT would have a detrimental impact on the performance and availability of intra-WAS/RLAN sharing. It is preferable to study a mechanism where an MFCN BS would signal its presence through broadcasting of a signal, with a successful reception when the received signal is at or above -75 dBm/80 MHz and the SINR conditions for the decoding of the signalling is met.

A large number of MFCN UEs indoor (UEs located in more than 70% of the locations) can still connect to the MFCN BS, even when the MFCN DL signal is reduced by 15 dB. Therefore, an additional mechanism may be required to prevent indoor UEs from connecting to 6 GHz MFCN networks, if the intention is to limit MFCN application to outdoors.

4.9.5 Conclusions

The WAS/RLAN indoor, MFCN with reduced BS *e.i.r.p.* on existing 3.5 GHz base station sites shared use scenario aims at enabling WAS/RLAN operation indoor and MFCN outdoor in the same geographical area.

The study indicates that, under the right combination of reduced MFCN *e.i.r.p.* and an improved mechanism for WAS/RLAN LPI APs in close proximity to MFCN BSs to detect them, the reduction in median SINR is limited for MFCN and WAS/RLANs, including in high population density areas, even under the assumption that WAS/RLAN transmits with a 100% activity factor and MFCN has 100% network loading.

The sharing scenario provides benefits in terms of energy consumption for mobile networks as it implies a reduced MFCN BS *e.i.r.p.*

The main drawbacks are that MFCN operators must rely on other bands to deliver indoor connectivity and that QoS cannot be guaranteed for either MFCN or WAS/RLANs as punctual interference would occur when MFCN UEs and WAS/RLAN operate in close proximity.

4.9.6 Opportunities for further studies

- Further studies may be required to confirm the optimal MFCN *e.i.r.p.* level to balance MFCN outdoor coverage/capacity and MFCN BS interference to indoor WAS/RLAN;
- Further studies would be required to identify and specify the best mechanism for an MFCN Base Station to signal its presence to WAS/RLANs in very close proximity;
- A mechanism enabling indoor MFCN UEs to avoid connection to an MFCN BS in the Upper 6 GHz band may provide additional benefits to minimise the QoS degradation risks to both MFCN and WAS/RLANs but would require additional investigation.

4.10 STUDY B3: MEDIUM POWER OUTDOOR MFCN AND INDOOR WAS/RLAN IN COPENHAGEN

4.10.1 Introduction

The study provides a detailed assessment of the sharing scenario, based on existing MFCN deployment in Copenhagen, with a focus on indoor WAS/RLAN and outdoor-only MFCN. In particular, the study demonstrates the additional benefits achieved by shared use of spectrum compared with single use of spectrum. The study also identifies the MFCN BS maximum *e.i.r.p.* leading to the maximum benefits for the end users.

The study is considering the throughput of MFCN, WAS/RLAN and combined MFCN and WAS/RLAN, as described here:

- The throughput figures for MFCN in this study are defined as the aggregate instantaneous average downlink throughput of three UEs, with the averaging performed within the 200 m MFCN cell range.
- The throughput figures for WAS/RLAN in this study are defined as the aggregate instantaneous average throughput of three instantaneously and simultaneously transmitting WAS/RLAN links, assuming a fixed path loss corresponding to a 9 m AP-STA distance, with the averaging performed within the 200 m MFCN cell range.

Note: the MFCN cell range, number of instantaneously transmitting WAS/RLANs and the WAS/RLANs' pathloss are subject to sensitivity analysis, in which case the definition of throughput varies accordingly.

The study examines the throughput within a single MFCN cell sector, for MFCN DL, MFCN UL or the WAS/RLANs deployed in the equivalent area. The study is trying to identify the optimal MFCN BS *e.i.r.p.* power level in terms of the achieved combined MFCN and WAS/RLAN throughput and determining that this scenario has a throughput benefit.

4.10.2 Technical parameters

The study considers, in a first simulation, an MFCN deployment where an MNO's existing 3.5 GHz network in the city centre of Copenhagen is augmented with MFCN 6 GHz base stations, and WAS/RLAN LPIs are deployed indoors. The average inter-site distance of 3.5 GHz base stations in Copenhagen is 298 m, corresponding to a MFCN cell range of 200 m, i.e. the network is significantly denser than the network assumed for ITU studies in preparation of WRC-23 (MFCN cell range in those studies is 300 m).

The study considers an MFCN BS *e.i.r.p.* of 67 dBm/80 MHz and assesses the impact of reducing the *e.i.r.p.* on the MFCN and WAS/RLAN capacity.

MFCN and WAS/RLAN are all operating on one 80 MHz channel.

MFCN UEs (outdoor) and WAS/RLANs (indoor) height are set at 1.5 m.

Locations of MFCN UEs and WAS/RLAN equipment are assumed to have a uniform random distribution within an MFCN cell and are assumed to be uncorrelated. The timing aspects, including the MFCN TDD factor and cell load as well as the activity factor of WAS/RLANs, are not taken into account in this study.

Option 3 (Recommendation ITU-R P.452-17 [11] and Recommendation ITU-R P.2108-1 [12]) is adopted for propagation, taking into account the real base stations in Copenhagen. Option 1 is adopted for building penetration loss. Recommendation ITU-R P.1238 [43] is leveraged to derive the WAS/RLAN coverage corresponding to specific assumptions about the WAS/RLAN received signal strength.

Three sensitivity analyses are conducted to assess:

- Replacing the real MFCN BS location with a theoretical network which aligns with the assumptions in section 2;
- The impact of thermally-efficient buildings;
- The impact of the WAS/RLAN received signal strength.

4.10.3 Study methodology

The study performs a Monte-Carlo analysis in the spatial domain, placing MFCN BS, MFCN UEs and WAS/RLAN LPIs, assessing the pathloss between nodes and deriving both wanted signal and interference. Accordingly, MFCN inter-cell interference and mutual interference between MFCN and WAS/RLAN is examined, but mutual interference between WAS/RLANs is not modelled. The SINR distribution is derived. For each point of the SINR distribution, the corresponding data rate is derived, then the throughput. The study calculates the maximum instantaneous data throughput that can be transmitted within a 200 m cell range by MFCN DL, MFCN UL or WAS/RLAN. Due to the assumed 100% activity factor (WAS/RLAN) and the 100% network loading factor (MFCN), this throughput is an upper bound of the geographically averaged throughput that can be delivered by either WAS/RLAN or MFCN in a reference area (typically one MFCN sector). The maximum instantaneous data throughput does not represent the WAS/RLAN or MFCN average traffic expected over the long term.

The throughput of MFCN DL and WAS/RLAN are derived separately. The available throughput, defined as the sum of MFCN DL and WAS/RLAN throughput, is determined.

The study does not take into account the timing domain, including MFCN frame format, WAS/RLAN channel access mechanisms, MFCN cell load, MFCN and WAS/RLAN activity factors, channel adaptation and retransmission mechanisms.

The simulation also assumes that a WAS/RLAN AP operating in a location where the received MFCN DL signal is on average above the EDT, would vacate the channel.

4.10.4 Results and implications for WAS/RLAN and MFCN

4.10.4.1 Considerations on location

- Locations of overlap where both WAS/RLAN and MFCN would be deployed: in urban areas, MFCN would aim at outdoor coverage while WAS/RLAN LPI would aim at indoor connectivity;
- Locations where only MFCN would be deployed: these are not considered in this study;
- Locations where only WAS/RLAN would be deployed: these are not considered in this study.

4.10.4.2 Main results

The study indicates that the MFCN performance is severely limited by interference, both indoors and outdoors, when the MFCN BS *e.i.r.p.* is 67 dBm/80 MHz, with an average downlink throughput of around 150 Mbps within the 200 m MFCN cell range in the absence of interference from WAS/RLANs. The study also indicates that the MFCN UL is limited by the power of the MFCN UE, especially indoor, even for modest cell radii.

The study indicates that three instantaneously and simultaneously transmitting WAS/RLAN links, assuming a fixed path loss corresponding to a 9 m AP-STA distance, with the averaging performed over the 200 m MFCN cell range, in aggregate deliver a throughput of around 1600 Mbps in the absence of interference from MFCN. Three indoor WAS/RLANs correspond to a population of around 5600 habitants per km² within the 200 m MFCN cell range.

The study indicates that sharing is possible under a range of MFCN BS *e.i.r.p.* levels, approximately between 27 dBm/80 MHz and 50 dBm/80 MHz.

The optimum sharing configuration depends on the regulatory objective as follows:

- When targeting maximum average spectral efficiency, the sharing optimum corresponds to a MFCN BS *e.i.r.p.* of 28 dBm/80 MHz. The aggregate WAS/RLAN throughput of three links is around 1600 Mbps and the average MFCN DL throughput is 96 Mbps within the 200 MFCN cell range, assuming that WAS/RLAN transmits with a 100% activity factor and MFCN has 100% network loading, and with the same assumptions and throughput definitions as above;
- For equal percentage throughput degradation, the sharing optimum is achieved at an MFCN BS *e.i.r.p.* of 40 dBm/80 MHz, enabling over 90+% of both WAS/RLAN and average MFCN DL throughput, assuming

that WAS/RLANs transmit with a 100% activity factor and MFCN has 100% network loading, and with the same assumptions and throughput definitions as above.

Increasing MFCN *e.i.r.p.* intensifies intercell interference, significantly impacting the downlink performance. In many instances, MFCN intercell interference exceeds WAS/RLAN interference, rendering the overall MFCN network less sensitive to interference from WAS/RLANs. The MFCN configuration results in a typical minimum pathloss of 77 dB between a WAS/RLAN and the MFCN BS AAS output (77 dB pathloss corresponds to a 20 dB Building Entry Loss, whereas in the simulation the BEL follows the full distribution).

Active WAS/RLANs with a 100% Activity Factor (AF) located in locations where the pathloss from the MFCN BS is 77 dB would contribute to a degradation in MFCN UL capacity of less than 5%.

4.10.5 Sensitivity analysis

The study indicates that the results are robust to significant variations of assumptions and input parameters, with the following trends:

- If the MFCN cell range is expanded from 200 m to 300 m while maintaining the same WAS/RLAN density, more WAS/RLAN APs would fall within the enlarged cell range. This greater number of WAS/RLAN APs can provide higher WAS/RLAN throughput within the expanded cell range;
- Expanding the MFCN cell range from 200 m to 300 m requires an increase in MFCN transmission power, but the resulting gain in throughput is limited to a single-digit percentage;
- The combined WAS/RLAN and MFCN throughput is increased (mostly due to increased WAS/RLAN throughput). However, the percentage of the throughput achieved at the optimum point, decreases, i.e. sharing is less efficient on larger cells;
- Thermally efficient buildings increase the MFCN BS *e.i.r.p.*, the combined WAS/RLAN and MFCN throughput and the percentage of throughput achieved at the optimal point. This improvement is expected, as such thermally efficient buildings provide better decorrelation between indoor and outdoor;
- Weak WAS/RLAN RSSI decreases the MFCN BS *e.i.r.p.*, the combined WAS/RLAN and MFCN throughput and the percentage of the throughput achieved at the optimum point.

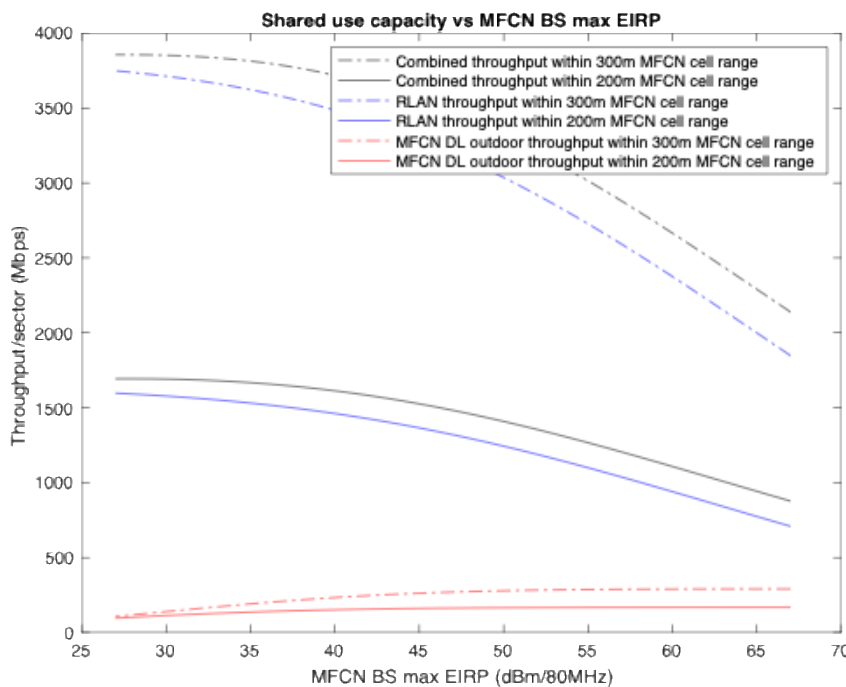


Figure 9: Shared use WAS/RLAN indoor throughput (three links) and MFCN outdoor throughput, averaged in a 200/300 m MFCN cell range

4.10.6 Conclusions

The throughput values in this study for MFCN are defined as the aggregate (of three UE) instantaneous average downlink throughput, where the averaging is performed within the 200 m MFCN cell range.

The throughput figures in this study for the WAS/RLAN case are defined as the aggregate instantaneous average throughput of three instantaneously and simultaneously transmitting WAS/RLANs links assuming a fixed path-loss corresponding to a 9 m AP-STA distance, where the averaging is performed within the 200 m MFCN cell range.

The study does not take into account the timing domain, including MFCN frame format, WAS/RLAN channel access mechanisms, MFCN cell load, MFCN and WAS/RLAN activity factors, channel adaptation and retransmission mechanisms.

Shared use of spectrum aiming at WAS/RLAN indoors and MFCN outdoors can deliver an overall throughput higher than the throughput enabled by only one of the two systems in the band, while delivering 90+% of the throughput of WAS/RLAN and MFCN, and assuming that WAS/RLAN transmits with a 100% activity factor and MFCN has 100% network loading, and with the same assumptions and throughput definitions as above. Shared use of spectrum requires limiting the MFCN BS *7e.i.r.p.* to a range between 27 dBm/80 MHz and 50 dBm/80 MHz, depending on the MFCN cell size, in order to avoid excessive reduction (40% or more) of the WAS/RLAN indoor throughput.

In a city like Copenhagen with a 5600 habitants per km² population density and a dense MFCN network (200 m MFCN cell range), MFCN are severely interference limited and can deliver an average DL throughput of approximately 160 Mbps/80 MHz outdoors, while WAS/RLAN can deliver 1600 Mbps indoors assuming three instantaneously and simultaneously transmitting WAS/RLAN links and a fixed path loss corresponding to a 9 m AP-STA distance , with the averaging performed within the 200 m MFCN cell range.

Increasing the size of the MFCN cell range or the population density only increases the gap between the throughput delivered by WAS/RLAN and the throughput delivered by MFCN.

WAS/RLAN interference to MFCN BS result in less than 5% reduction in MFCN UL throughput, suggesting that a cross-technology sensing mechanism may not be necessary.

4.10.7 Opportunities for further studies

The study only assesses the overall throughput and does not estimate the impact on other QoS metrics, such as latency and reliability.

Should there be an interest in leveraging the Listen Before Talk WAS/RLAN mechanism to improve coexistence between WAS/RLAN indoors and MFCN outdoors, further studies are required to ensure that WAS/RLAN APs detecting an MFCN DL signal above the EDT vacate the channel. Alternatively, a cross-technology signalling mechanism could be leveraged, as discussed in Study B2 (see section 4.9). While the WAS/RLAN EDT protects MFCN UEs from excessive interference from WAS/RLANs, MFCN UEs in this study are assumed to be outdoor. Further study may be required to determine whether MFCN UEs must implement a sensing mechanism to avoid causing interference to WAS/RLANs when attempting to connect to the MFCN BS from indoors. MFCN UEs should detect WAS/RLAN APs and Terminals in close proximity and, upon detection of a WAS/RLAN at a signal level above EDT, avoid UL transmission.

4.11 STUDY C2: INTERFERENCE FROM WAS/RLAN TO MFCN DOWNLINK

4.11.1 Introduction

The coexistence analysis presented in this study aims at establishing the scale of the issues relating to the simultaneous co-channel operation of MFCN and WAS/RLANs at the same time and place in the Upper 6 GHz band. The study assumes only the standard WAS/RLAN EDT as the detection/mitigation mechanism. The study provides a model for the interference from WAS/RLANs to MFCN downlink, both indoors and outdoors.

The results of the study indicate that in the absence of any additional measures, there is a risk of harmful interference from WAS/RLANs to MFCN downlink, and of degradation in the MFCN performance if they are to operate co-channel in the same geographic area and at the same time.

In particular, the following sections summarise the key elements relating to the case of harmful interference from WAS/RLAN equipment to MFCN UE.

4.11.2 Sharing scenario description

WAS/RLAN's channel access mechanism allows WAS/RLAN equipment to operate under a general authorisation regime in a decentralised manner and in competition with an indeterminate number of other co-channel WAS/RLAN equipment.

Accordingly, WAS/RLAN equipment assess the occupancy of the channel by sensing the presence of received signals over the air. If the received signal powers are above specific thresholds, WAS/RLANs equipment must cease/defer their transmissions until such time as the channel is assessed to be free and available; this is also referred to as "listen-before-talk" (LBT).

The study assumes that WAS/RLANs use the standard EDT of -84 dBm/MHz (corresponding to -65 dBm/80 MHz). No additional sharing/detection mechanisms is assumed. However, the WAS/RLAN EDT of -65 dBm/80 MHz is 31 dB greater than the minimum power (sensitivity) at which MFCN signals can be decoded by an MFCN UE (around -96 dBm/80 MHz). As a result, WAS/RLAN equipment would be unable to detect the presence of MFCN downlink signals over certain proportions of an MFCN indoor coverage area and would accordingly consider the channel to be available for WAS/RLAN transmissions, thereby potentially causing harmful co-channel interference to MFCN both indoors and outdoors.

4.11.3 Technical parameters

The study models MFCN DL emissions from a total of 19 sites in a hexagonal arrangement with three MFCN BSs, or cells, per site (i.e. a total of 57 BSs), where each BS simultaneously forms a beam towards each of three MFCN UEs located in its cell. The inter-site distance is 450 metres and corresponds to an MFCN cell radius of 300 metres.

The study considers a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz and a WAS/RLAN *e.i.r.p.* of 23 dBm/80 MHz. Both MFCN and WAS/RLAN are assumed to be operating co-channel in a channel bandwidth of 80 MHz.

The locations of MFCN UEs and WAS/RLAN equipment are assumed to have a uniform random distribution within an MFCN cell but are also assumed to be correlated with respect to each other. The WAS/RLAN interferer and MFCN UE receiver are both assumed to be at a height of 1.5 metres above ground, and with a horizontal separation of 0.5 to 10 metres between them, at the moment where they are actively transmitting and receiving, respectively. The timing aspects, including the activity factor of WAS/RLANs, are not taken into account in this study.

Radio propagation from MFCN BSs to the UEs is modelled according to ETSI TR 138 901, section 7.4 [13], with low-loss (glass and concrete) and high-loss (infra-red reflecting glass and concrete) modelled with probabilities of 80% and 20%, respectively. Radio propagation from the WAS/RLAN equipment to the MFCN UE, corresponding to separations of 0.5 to 10 metres, is modelled as free space path loss, and where applicable, in conjunction with a 15 dB brick wall penetration loss.

4.11.4 Methodology

In order to calculate the probability of a WAS/RLAN equipment transmitting co-channel with MFCN and within the coverage area of MFCN in the Upper 6 GHz band – and thereby potentially causing harmful interference to nearby MFCN UE – the study uses a Monte Carlo analysis to determine the statistics of the total (both wanted and unwanted) MFCN downlink signal power received at different locations within an MFCN cell, and compares this with the EDT of WAS/RLAN. The term "unwanted" here refers to MFCN inter-cell interference.

The study then calculates the impact of the emissions from a single WAS/RLAN equipment on the downlink signal-to-interference ratio (SINR) and downlink throughput of a nearby MFCN UE at different locations within an MFCN cell. The study models separations of 0.5 metre to 10 metres between the WAS/RLAN interferer and MFCN UE receiver at the moment where the former transmits and the latter receives. The timing aspects, including the activity factor of WAS/RLANs, are not taken into account in this study.

4.11.5 Results and implications for WAS/RLAN and MFCN

The modelling, based on a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz and an average building penetration loss of 20 dB, indicates that there is a likelihood that the MFCN downlink signal powers would not exceed the WAS/RLAN EDT, and that WAS/RLAN radios would not be able to detect the existence of MFCN downlink in around 47% of locations indoors and around 0% of locations outdoors within the coverage area of MFCN. Stated differently, the modelling indicates that WAS/RLAN access to spectrum would be prevented/deferred in virtually all locations outdoors, and 53% of locations indoors.

The modelling also indicates the following:

- Where a WAS/RLAN equipment and an MFCN UE are both located indoors and 10 metres apart, the MFCN downlink throughput would be degraded as a result of emissions from the WAS/RLAN equipment and would be reduced to zero in around 49% of the locations within an MFCN cell if the UE was within 10 m of a WAS/RLAN AP that had received MFCN signals below the EDT and continued to transmit at the same time as the UE was receiving data (up from 12% in the absence of interference from WAS/RLAN).
- Where a WAS/RLAN equipment and an MFCN UE are both located outdoors, the MFCN downlink throughput would not be affected (because the EDT of WAS/RLANs would be triggered and WAS/RLANs would not transmit or would defer transmissions), with the MFCN downlink throughput being zero in around 3% of outdoor locations within the coverage area of the MFCN (i.e. within an MFCN cell) in the absence of interference from WAS/RLAN.
- Where a WAS/RLAN equipment is indoors, but the MFCN UE is outdoors, the building penetration loss would mitigate the impact of interference, and – assuming an indoor-to-outdoor loss of 15 dB that is consistent with a brick wall – the MFCN downlink throughput would be reduced to zero in up to 40% of outdoor locations within an MFCN cell if the UE was within 10 m of an indoor WAS/RLAN AP that had received MFCN signals below the EDT and continued to transmit at the same time as the UE was receiving data (up from 3% in the absence of interference from WAS/RLAN) within the coverage area of the MFCN (i.e. within an MFCN cell), depending on interferer-victim separation of 0.5 to 10 metres.

The above results indicate that under the modelled conditions, and based on a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz, the co-channel sharing between MFCN and WAS/RLAN would degrade the capacity/coverage of MFCN downlink for UEs that are indoors or outdoors, and as a result of interference from indoor WAS/RLAN equipment that is within 10 m and which continues transmit at the same time as the UE is receiving data.

4.11.6 Discussion on benefit/drawbacks of studied sharing scenario

Co-channel operation of MFCN and indoor WAS/RLANs at the same time and place is challenging for an MFCN BS *e.i.r.p.* of 72 dBm/80 MHz, as interference from indoor WAS/RLAN equipment to MFCN UEs would result in degraded MFCN DL throughput/coverage indoors and outdoors in a large proportion of locations within an MFCN cell if a transmitting indoor WAS/RLAN was within 10 m of a receiving UE.

The impact of interference on MFCN would be expected to be greater if the MFCN BS *e.i.r.p.* was reduced, as this would result in WAS/RLAN transmissions in a greater proportion of indoor locations (because the WAS/RLAN EDT would not be triggered at an increasing number of locations) and the weaker received MFCN signals at UEs would mean that the UEs both indoors and outdoors would be more susceptible to interference from WAS/RLANs.

It is noted that while this study uses a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz, another study (Study E1 (see section 5.1)) indicates that MFCN BS *e.i.r.p.* of 81 dBm/100 MHz or greater is necessary to avoid poor MFCN throughputs to outdoor users, particularly those at cell-edge who are either located far from the MFCN BS, or whose experience is adversely affected by obstructions and shadowing in dense urban environments.

The potential for unpredictable disruptions to the indoor and outdoor MFCN downlink throughput/coverage – and hence to the QoS delivered to the customers – as a result of an indeterminate number of co-channel WAS/RLAN equipment in the proximity of UEs could reduce the value of the Upper 6 GHz band for MFCN operators and could compromise their incentives to invest in MFCN infrastructure in the band.

4.11.7 Conclusions

In summary, the study concludes that, for a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz, co-channel operation of indoor WAS/RLANs with MFCN at the same time and place would result in undue interference to the MFCN downlink both indoors and outdoors, and that additional mitigation measures would be required to enable sharing. Specifically, the results indicate that the indoor and outdoor MFCN downlink throughputs would be reduced to zero in up to 49% and 40% of locations within an MFCN cell, respectively, where there is a WAS/RLAN AP that continues to transmit within 10 m of the MFCN UE.

The impact of interference from WAS/RLANs on the performance of MFCN DL would be expected to be greater with MFCN BS *e.i.r.p.* below 71.6 dBm/80 MHz. This is because:

- a) the WAS/RLANs would fail to detect the presence of MFCN BSs in a greater proportion of locations within an MFCN cell, and would therefore continue to transmit, potentially causing harmful interference to a greater number of nearby UEs, and
- b) the MFCN UEs would be more susceptible to interference from WAS/RLANs as the UEs would be operating with a lower wanted MFCN downlink signal as a result of reduced MFCN BS *e.i.r.p.*

4.11.8 Opportunities for further studies

The potential for mutual interference between WAS/RLANs and MFCN uplink is for further study.

4.12 STUDY C3: INTERFERENCE FROM MFCN DOWNLINK TO WAS/RLAN

4.12.1 Introduction

The coexistence analysis presented in this study aims at establishing the scale of the issues relating to the simultaneous co-channel operation of MFCN and WAS/RLANs at the same time and place in the Upper 6 GHz band. The study provides a model for the interference from MFCN downlink to WAS/RLANs, both indoors and outdoors.

The results of the study indicate that in the absence of any additional measures, there is a risk of interference from MFCN BS to WAS/RLANs, and of degradation in the performance of WAS/RLAN if they are to operate co-channel in the same geographic area and at the same time.

In particular, the following sections summarise the key elements relating to the limitations that would apply to WAS/RLAN communications, both indoor and outdoor, due to MFCN transmissions in the downlink.

4.12.2 Sharing scenario description

This study analyses the potential for harmful co-channel interference from MFCN downlink to WAS/RLANs.

MFCN downlink signals would impact the operation of co-channel WAS/RLANs in two important ways:

- Firstly, if the level of the received MFCN downlink signals is greater than the WAS/RLAN EDT, WAS/RLAN equipment would assess the channel to be occupied and therefore cease/defer their transmissions, thereby resulting in zero WAS/RLAN throughput;
- Secondly, where the WAS/RLAN EDT is not exceeded, and the WAS/RLAN equipment transmit, the MFCN downlink signals would reduce the WAS/RLAN throughput; or for the same throughput, they would reduce the WAS/RLAN communication range.

4.12.3 Technical parameters

The study models MFCN DL emissions from a total of 19 sites in a hexagonal arrangement with three MFCN BSs), or cells, per site (i.e. a total of 57 BSs), where each BS simultaneously forms a beam towards each of three MFCN UEs located in its cell. The inter-site distance is 450 metres and corresponds to an MFCN cell radius of 300 metres.

The study considers a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz with both MFCN and WAS/RLAN assumed to be operating co-channel in a channel bandwidth of 80 MHz.

The locations of the WAS/RLAN equipment are assumed to have a uniform random distribution within an MFCN cell at a height of 1.5 metres above ground.

Radio propagation from MFCN BSs to the UEs is modelled according to ETSI TR 138 901, section 7.4 [13], with low-loss (glass and concrete) and high-loss (infra-red reflecting glass and concrete) modelled with probabilities of 80% and 20%, respectively. Radio propagation from the WAS/RLAN AP to STA is modelled as free space path loss.

4.12.4 Methodology

The study uses a Monte Carlo analysis to determine the statistics of the total (both wanted and unwanted) MFCN downlink signal power received at different locations within an MFCN cell, in order to quantify the probability of MFCN downlink signals causing harmful co-channel interference to WAS/RLAN radios located within the coverage area of MFCN in the Upper 6 GHz band. The term “unwanted” refers to MFCN inter-cell interference.

The study then calculates the impact of the emissions from the MFCN BSs on the communication range of WAS/RLANs at different locations within an MFCN cell. As described above, this impact can be due to the triggering of the EDT of WAS/RLANs, or a degradation in SINR at the WAS/RLAN equipment.

4.12.5 Results and implications on WAS/RLAN and MFCN

The modelling, based on a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz, indicates the following:

- WAS/RLAN communications indoors
The presence of MFCN DL signals would prevent or defer WAS/RLAN transmissions in around 53% of indoor locations within the coverage area of an MFCN, thereby reducing WAS/RLAN throughput and range to zero at such locations. Furthermore, WAS/RLAN communication range would be reduced to less than 5% of what it would be in the absence of MFCN downlink signals, in an additional 7% of indoor locations (so around 60% of indoor locations would have no or little WAS/RLAN range) within the coverage area of an MFCN (i.e. within an MFCN cell).
- WAS/RLAN communications outdoors
The presence of MFCN DL signals would prevent or defer WAS/RLAN radios transmissions in almost all outdoor locations within the coverage area of an MFCN (i.e. within an MFCN cell), thereby reducing WAS/RLAN throughput and range to zero at such locations.

4.12.6 Conclusions

The study concludes that, for a MFCN BS *e.i.r.p.* of 71.6 dBm/80 MHz, co-channel operation of WAS/RLANs with MFCN at the same time and place would prevent/defer transmissions of WAS/RLAN equipment located outdoor and would result in significant limitations to WAS/RLAN communications for WAS/RLAN equipment located indoors. Specifically, WAS/RLAN communications would be prevented/deferred in 53% of indoor locations within an MFCN cell, and WAS/RLAN communications range would reduce to 5% of what it would be in the absence of interference from MFCN in an additional 7% (thereby 60% in total) of indoor locations within an MFCN cell.

4.12.7 Opportunities for further studies

The potential for interference from WAS/RLANs to MFCN uplink is for further study.

4.13 STUDY C9: MACRO-CELLULAR MFCN AND CO-CHANNEL WAS/RLAN WITHOUT ADDITIONAL SHARING MECHANISMS

4.13.1 Introduction

The coexistence between macro-cellular MFCN using 72.6 dBm/100 MHz e.i.r.p. and co-channel WAS/RLAN was studied without additional sharing mechanisms.

A separate scenario was considered to simulate only WAS/RLAN VLP interference to MFCN DL, based on WAS/RLAN LPI deployment (as a means to characterise the behaviour of WAS/RLAN VLPs without LBT).

The results show that performance of an MFCN system would be degraded if co-channel WAS/RLAN LPI and VLP operate in the same area without additional sharing mechanisms. Also WAS/RLAN LPI would experience significant interference from the MFCN system.

4.13.2 Sharing scenario description

A regular MFCN hexagonal grid with 500 metres inter-site distance was used, with 7 sites and 21 cells using wrap-around. Two different deployments of MFCN UEs and WAS/RLAN devices were considered: a uniform distribution, and a clustered deployment of devices. Such clusters could be restaurants and shopping areas, for example.

Interference across systems was simulated. For the MFCN system as the victim, the performance under RLAN interference was compared to performance without WAS/RLANs. For the WAS/RLAN system as the victim, interference statistics were collected from the MFCN transmissions, without intra-system interference (i.e. no interference from WAS/RLANs).

A field trial in section 5.2.6 (one BS, one AP one UE in two locations, locked on the same channel and located on the same corridor, representing a special case of a clustered deployment) of an idle WAS/RLAN LPI AP causing interference to MFCN full buffer DL and UL is described to infer from it the potential of VLP impact on MFCN DL. By means of free space loss calculation, the study suggests that interference experienced by MFCN UEs within 13 metres of an LPI AP would be similar to that within 4 metres of a VLP client, both corresponding to 10% throughput reduction.

As this study uses a system-level simulator that was not mean to model throughput degradation due to bursty interference and therefore does not output the throughput degradation of 20% observed in the field trial when the activity factor was 0.86%. To address this, the concept of an “effective” activity factor, replacing the actual activity factor from the duty cycle, is introduced. For traffic profiles like periodic video packet generation, the study proposes using a 20% “effective” activity factor instead of the actual 0.86%. To derive this effective activity factor, the study adopted a value that matched the highest of the two mean throughput degradation levels observed in the trial (i.e. 20%).

For the WAS/RLAN VLP interference scenario, the same simulation setup was used except for the WAS/RLAN deployment and the effective RF activity factor of 20% for the VLP devices was used.

Under the assumption of network congestion from WAS/RLAN and MFCN spectrum usage, the VLP client is assumed to fail to select a clear channel.

4.13.3 Technical parameters

The parameters were according to section 3.1 of this Report, with some modifications, listed below.

The 500 m MFCN inter-site distance leads to a density of 11.5 BS/km². Both MFCN and WAS/RLAN systems assumed fully overlapping 160 MHz channel bandwidth. All MFCN UEs and WAS/RLAN devices are at 1.5 m height.

The simulation drops 10 MFCN UEs and 40 WAS/RLAN (LPI and VLP) devices per cell. This assumes the highest WAS/RLAN deployment scenario (Scenario B High) and a dense population density of 11500 inhabitants/km². Two distributions for locations of MFCN UEs and WAS/RLAN LPI devices are assumed: uniform and clustered. In the clustered deployment, there are 2 clusters of 20 metre radius per MFCN cell, and all MFCN UEs and WAS/RLAN LPI devices are distributed uniformly within these clusters. Both indoor and outdoor locations were considered.

In the WAS/RLAN VLP interference scenario, 4 WAS/RLAN VLP devices per cell were dropped (i.e. 10% of the total WAS/RLAN deployment according to the device category distribution), in the same cluster formation as described above.

4.13.4 Study methodology

A detailed system-level simulator was used to assess the interference from MFCN to WAS/RLAN and from WAS/RLAN to MFCN. The simulator is fully dynamic and is typically used to evaluate various PHY and MAC layer feature proposals within the 3GPP standardisation scope. For the purposes of the study in PT1, many of the available features were disabled. The focus of the simulations was to excite the transmitters at the desired power level and resource utilization, and activate the receivers to collect wanted and interfering signal level statistics. Hence the results would not reflect absolute performance of the MFCN system.

For the WAS/RLAN system, the model is based on simple transmitter and receiver characteristics.

Performance metrics and interference statistics are collected from all 21 cells. Each cell has the same characteristics, thanks to the wrap-around. When MFCN is the victim system, a single WAS/RLAN per cell is randomly chosen to transmit during each time interval. MFCN performance metrics (successfully received transport blocks, SINR) are collected. When WAS/RLAN is the victim system, I/N statistics are collected at all 40 WAS/RLAN nodes in the cells.

In the WAS/RLAN VLP interference scenario, on average 0.8 WAS/RLAN devices per MFCN cell were transmitting (i.e. assuming 4 devices per cell, and with an effective 20% RF activity factor reflecting the impact to MFCN DL that was observed in the field trial).

4.13.5 Results and implications in WAS/RLAN and MFCN

For MFCN downlink as the victim, the WAS/RLAN impact is marginal with uniform device distribution; the distance between the receiving MFCN UE and the transmitting WAS/RLAN device is typically rather large, which makes significant I/N occurrences unlikely.

In the clustered device deployment, the interference impact from WAS/RLANs in the same cluster as the MFCN UEs (assuming WAS/RLAN LPI is always located within 40 m from a UE) is clearly visible. The downlink median throughput is degraded by 26%, and the cell edge (5th percentile) by 53%. The downlink median SINR is degraded by 0.8 dB, and the cell edge SINR by 1.5 dB.

There is impact also in the uplink direction from WAS/RLAN deployments. The uplink median throughput is degraded by 17% due to interference from WAS/RLAN, and the uplink median SINR is degraded by 1.3 dB. Clustered device deployment (where WAS/RLAN and UE locations are assumed to be correlated) is marginally worse than uniform distribution.

For WAS/RLAN as the victim system, using the uniform device distribution, about 30% to 35% of the interference samples are noise-limited (i.e. I/N < -10 dB). About 15% to 20% of the samples exceed the LBT energy detection threshold level (-85 dBm/MHz = -63 dBm/160 MHz). About 35% of the samples are clearly interference-limited (i.e. I/N > 10 dB), leaving 15-20% of samples interference-limited and below the ED threshold. For the majority of the RLAN devices in the uniform distribution case, interference is significantly stronger during the MFCN DL time slots (75% of the time), compared to the UL time slots (25% of the time).

For the clustered device deployment, only about 8% to 10% of the samples are noise-limited (i.e. $I/N < -10$ dB); this is significantly fewer than with the uniform device distribution. About 30% to 40% of the samples exceed the LBT threshold level (-85 dBm/MHz = -63 dBm/160 MHz). About 60% to 65% of the samples are clearly interference-limited (i.e. $I/N > 10$ dB), leaving 25-30% of samples interference-limited and below the ED threshold. The results indicate that a clustered deployment assumption is much more detrimental for the WAS/RLAN than a uniform distribution assumption; some WAS/RLANs are clearly impacted by the MFCN UL transmissions.

For MFCN downlink as the victim in the WAS/RLAN VLP-only scenario with clustered deployment assumption, and in absence of a sharing mechanism, it was observed that the DL throughput can be impacted by 9.1% for the median MFCN user, and by 40% for the cell edge user.

The study presents the aggregate impact of indoor and outdoor as a single deployment scenario and does not provide separate results for indoor or outdoor only deployments.

4.13.6 Conclusions

The results show that performance of an MFCN system would be degraded (with downlink degraded under the assumption that active WAS/RLAN always operate within 40 m from UEs) if co-channel WAS/RLAN operates in the same area without additional sharing mechanisms. Also 20% of WAS/RLAN LPI would experience significant interference ($I/N > 10$ dB) from the MFCN system, while 20-35% of WAS/RLAN LPI would back off as exceeding the LBT threshold. The deployment assumption makes a difference to the severity of interference, a clustered device deployment assumption being worse for coexistence. Further study would be required to understand the impact for indoor-only and outdoor-only scenarios.

4.14 STUDY A4: 6 GHZ MFCN DOWNLINK SPECTRAL EFFICIENCY CONSIDERATIONS WITH REDUCED BS E.I.R.P.

4.14.1 Introduction

This site-specific study shows the impact on the DL spectral efficiency (SE) of an Upper 6 GHz standalone MFCN macro network when the BS *e.i.r.p.* is reduced, according to one of the proposed solutions to enable shared use of the band.

4.14.2 Technical parameters

Building losses are categorised with one-third classified as high-loss (30% infrared reflecting glass and 70% concrete wall) and the remainder as low-loss (30% standard glass and 70% concrete wall). 70% of the traffic occurs indoors. The MFCN macro deployment in this study considers an inter-site distance (ISD) of 450 m. MFCN BSs are placed on rooftop edges, 3 m above buildings with heights around 28 m.

For the MFCN array configuration, the study uses an 8x16 array with the subarray extended model [20], which has a subarray size of 3x1. Downlink beamforming is performed using a grid-of-beams approach similar to 3GPP New Radio (NR) Type I codebook based on two-dimensional discrete Fourier transform (2D-DFT) beams [32]. For each UE, the beam that maximises its signal-to-interference-plus-noise ratio (SINR) is selected. Additionally, UEs with 4 receiver antenna branches are assumed, which implement a maximum-ratio combining (MRC) receiver, providing additional UE gains of up to 6 dB. Furthermore, the mapping of SINR to throughput considers two polarisations/streams, packet retransmissions, and is based on the 3GPP Tapped Delay Line A (TDL-A) channel model [13] (representing a NLOS channel profile), with users moving at walking speeds (i.e. 3 km/h).

4.14.3 Study methodology

This study considers Covent Garden area, London, covering approximately 1.69 km² of flat terrain with green spaces. Most buildings are under 28 m tall, with around 70% not exceeding 20 m, although there are some exceptions exceeding 100 m in height.

A site-specific ray-tracing like propagation model [33] is used accounting for multiple different propagation mechanisms such as specular reflections, diffuse scattering, diffraction, and transmission. Additionally, traffic load conditions across all cells are simplified to enable throughput calculations without the scheduler queuing impact. This assessment helps evaluate the full potential of the Upper 6 GHz network.

It is important to consider that the differences between parameters used in this study and those in section 2 may make the comparison between the throughput results with other studies challenging.

4.14.4 Results and implications for WAS/RLAN and MFCN

The findings indicate that a reduction in MFCN BS *e.i.r.p.* from 83 dBm/100 MHz to 77 dBm/100 MHz results in:

- the Upper 6 GHz mobile network median SE (50th percentile) degrades by 15.3%, and the cell-edge SE (5th percentile) degrades by 71.7%.

Additionally, if the MFCN BS *e.i.r.p.* is reduced from 83 dBm/100 MHz to 65 dBm/100 MHz:

- the Upper 6 GHz mobile network median SE (50th percentile) degrades by 57.1%, and the cell-edge SE (5th percentile) becomes 0 bit/s/Hz as no transmissions are possible.

It is worth noting that cell-edge performance is one of the 5G key performance indicators used as reference to determine the user experienced data rate in a network, as indicated in the Report ITU-R M.2410 [34].

4.14.5 Discussion on benefit/drawbacks of studied sharing scenario

This study has shown a negative performance impact on the MFCN, in terms of throughput and consequently spectral efficiency, as well as coverage due to the effective shrinking of the cell.

These impacts on throughput and coverage would mean that operators may not be able to fully exploit the benefits of the re-use of existing sites from lower bands, in order to provide sufficient coverage and meet the demands of end user connectivity experience and may therefore need to deploy additional sites in certain areas. This increase in sites would imply increased costs for operators.

If densification is employed by operators in certain areas as a consequence of power restrictions in order to recover throughput and coverage, it could have the unintended consequence of causing a similar level of interference to WAS/RLAN as with the full power scenario, thus removing, or at least limiting, any benefit of this sharing solution in practice. This is explored further in study A5 (see section 4.20).

The possible need for consequential densification in this scenario is mentioned in section 2.4.

4.14.6 Opportunities for further studies

Further studies could consider evaluating the UL direction to better understand its performance.

The impact of interference to WAS/RLAN resulting from densification of MFCN due to restrictions on BS *e.i.r.p.* should also be understood further.

4.14.7 Conclusions

In conclusion, reducing the MFCN BS *e.i.r.p.* as a sharing solution would result in reductions in performance from a network and user perspective of MFCN macro-cell coverage and capacity. Performance of both the overall SE of the Upper 6 GHz mobile network and the cell edge performance is shown to be impacted.

4.15 STUDY C4 AND STUDY C5: NETWORK COVERAGE STUDY

4.15.1 Introduction

This study assesses the performance of MFCN with outdoor base stations and WAS/RLAN systems with access points placed indoors when both are using the Upper 6 GHz spectrum band in the same area. The results assess the following interference scenarios that can be expected with such deployments:

- Interference from WAS/RLAN to both indoor and outdoor MFCN UEs in the downlink;
- Interference to WAS/RLAN from both MFCN BS and UE;
- Interference to MFCN BS uplink from WAS/RLAN.

For ease of understanding and to simplify reproducibility in assessing a number of complex interference scenarios a basic propagation modelling capturing the main effects relevant for the analysis is used. This is complemented by a detailed coverage study of MNO's macro-cell network in a large European city to assess the indoor signal levels which can be expected when Upper 6 GHz is deployed for MFCN in urban areas.

Other than considering the EDT for WAS/RLAN no other sharing mechanisms were assumed in the analysis.

4.15.2 Technical parameters

4.15.2.1 Theoretical analysis

The parameters for the theoretical analysis are aligned with those from section 2 of the Report.

The following WAS/RLAN parameters are assumed:

EDT: -84 dBm/MHz (assuming $P_{max} = 23$ dBm);

Noise figure: 10 dB.

- The MFCN deployment is assumed as an urban macro-cell with a range of 300 m (representing an ISD of around 450-500 m).

The propagation model is summarised as:

LOS paths: free space;

NLOS paths: excess loss of 30 dB;

Building loss: 30 dB (corresponding to high loss model from ITU-R M.2412 [35]).

4.15.2.2 Coverage analysis

The coverage is calculated using a calibrated ray tracing prediction model, used for network planning today, with detailed building and clutter information (as shown in Figure 10). Further information is provided in Table 22.

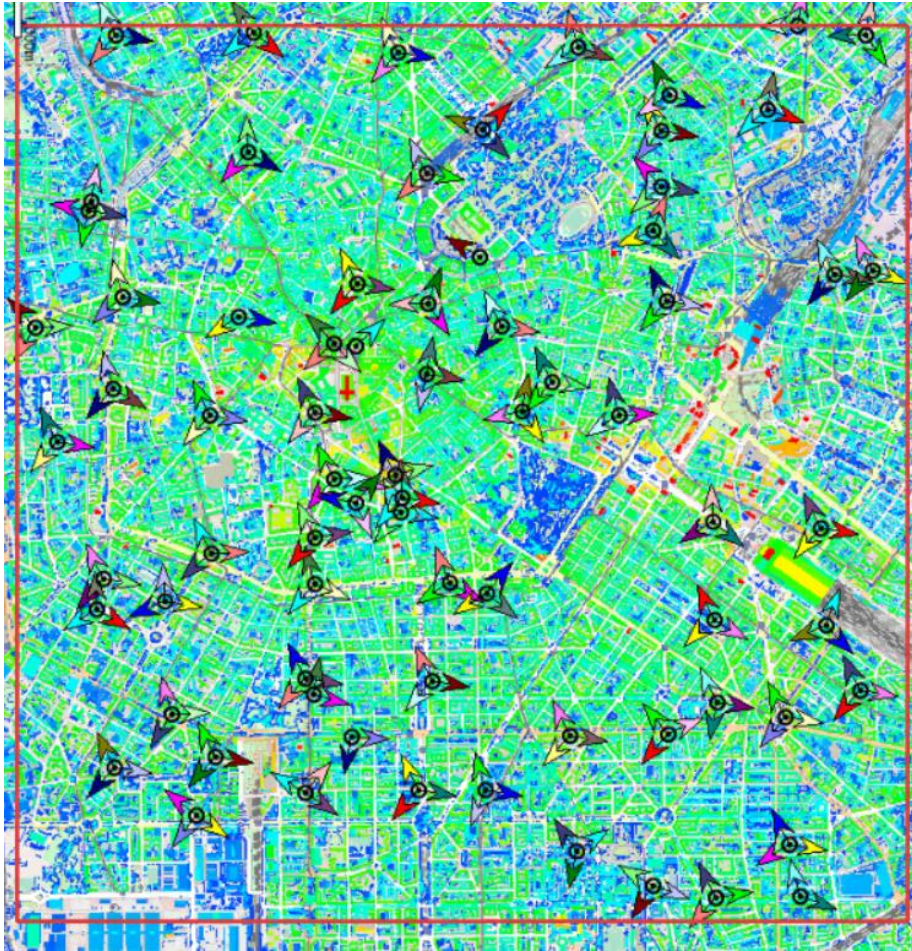


Figure 10: Real urban network analysis area

Table 22: Real urban network details

Network detail	Value
Network Area	Approx 5x5 km
Environment	Dense Urban/Urban
Base Station Sites	74 sites (mostly 3 sectors)

Key parameters used to calculate coverage are summarised in Table 23.

Table 23: Key parameters for coverage analysis

Parameter	Value
Base Station <i>e.i.r.p.</i>	74 dBm/100 MHz 80 dBm/100 MHz
Building Penetration/ Outdoor-to-Indoor Loss	Variable loss depending on building type & location within building Average Outdoor-to-Indoor Loss = 26 dB
Receiver height	1.5 m

4.15.3 Study methodology

The analysis uses the model and coverage analysis detailed above to assess the levels of interference between WAS/RLAN and MFCN.

4.15.4 Results and implications for WAS/RLAN and MFCN

The theoretical analysis indicates the following:

- Interference from WAS/RLAN to MFCN downlink
 - MFCN signal levels are below the EDT for any indoor location more than ~50 m from the BS
 - WAS/RLAN at such locations would continue to transmit, resulting in signal levels around 50 dB higher than the MFCN signal level assuming a 5m separation from an indoor MFCN UE, and signal levels around 35 dB higher than the MFCN signal level assuming 25 m separation from an indoor UE, effectively blocking MFCN downlink indoor applications in these areas while the WAS/RLAN is actively transmitting.
 - A potential reduction of EDT of around 10 dB increases the area where MFCN is not interfered from WAS/RLAN to around 100 m, but indoor locations beyond this distance would remain where WAS/RLAN continues to transmit, resulting in the WAS/RLAN to indoor MFCN downlink interference levels described above.
 - Indoor WAS/RLAN transmissions could also cause interference above the thermal noise floor to outdoor UEs up to 50 m from the WAS/RLAN device. This interference level varies from around 20 dB above the UE thermal noise floor for outdoor UEs very close (~5 metres) to the indoor WAS/RLAN, to 0 dB for outdoor UEs at around 50 m from the indoor WAS/RLAN (i.e. equal to the UE thermal noise floor resulting in a 3 dB increase in noise floor). This is based on the assumption of a relatively high BEL of 30 dB, lower losses would result in higher levels of interference across these distances and an impact (in terms of interference equal to or greater than the UE noise floor) over larger distances.
- Interference from mobile downlink to WAS/RLAN
 - WAS/RLAN devices would experience interference levels at or in excess of the WAS/RLAN noise floor across all indoor areas up to 300 m from the MFCN BS.
 - At half the cell range (150 m), MFCN signal levels are around 5 dB higher than the WAS/RLAN receiver noise floor, which would result in a degradation of performance.
 - Reducing the MFCN BS power by 10 dB would result in a reduction in the interference to WAS/RLAN networks. In this case the interference level to WAS/RLAN networks is equal to the receiver's noise floor at distances up to 90 m, instead of 300 m (without the 10 dB power reduction)
 - In the case of power reduction the EDT would be triggered in fewer areas, from distances less than 30 m without 10 dB power reduction to less than 10 m with 10 dB power reduction, resulting in increased WAS/RLAN operation closer to the MFCN BS.
 - It should be noted the interference levels described above would be greater for buildings with lower losses and/or taller buildings with more direct line-of-sight paths to the MFCN BS.
- Interference from WAS/RLAN to mobile uplink
 - As indicated for the downlink case, WAS/RLAN devices transmitting as a result of failure to trigger the EDT may also cause interference in the uplink to MFCN BS receivers.
 - Note that for the uplink TDD time slots the MFCN base station is not transmitting and would not trigger energy detection at the WAS/RLAN devices. For the uplink, energy detection would have to be triggered by the signal from nearby MFCN UEs, which transmit with lower power and may experience higher attenuation losses. Therefore triggering energy detection cannot be guaranteed.
 - For these cases where the EDT is not triggered by nearby MFCN UEs or another mechanism, an indoor WAS/RLAN device with a LOS path within 50 m from the MFCN BS could cause desensitisation of the uplink reception at the BS (i.e. interfere at a level equal to or greater than the noise floor of the MFCN BS), resulting in uplink performance and capacity degradations for all MFCN UEs in the cell. Note the receiver noise figure of an MFCN BS can be expected to be lower than that of an MFCN UE,

resulting in a lower noise floor, therefore from this perspective this is a conservative estimate of the desensitisation.

- An indoor WAS/RLAN device in a building with lower building entry loss than 30 dB, or an open window, would cause even higher interference levels at the MFCN BS receiver.
- Lack of EDT triggering by MFCN UEs could result in several concurrent WAS/RLAN transmissions meaning higher aggregated levels of interference to MFCN BS receivers
- Interference from mobile uplink to WAS/RLAN
 - Outdoor UEs close to cell edge operating at high TX powers could cause interference to indoor WAS/RLAN devices at levels higher than the noise floor of WAS/RLAN receivers within 50 m range

To validate the theoretical urban area model a coverage analysis was conducted for a real MFCN layout in a large European city. Indoor coverage levels across the area for different BS power levels are shown in Figure 11.

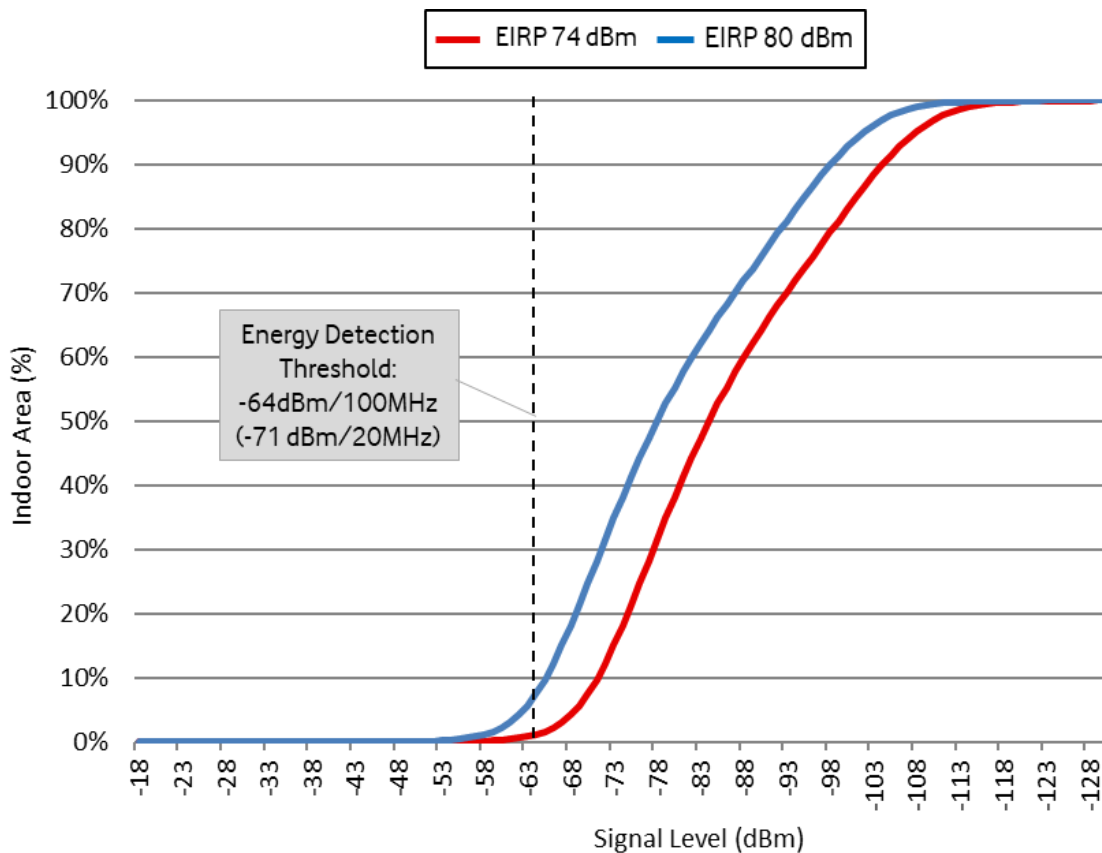


Figure 11: Urban Indoor Coverage Distribution

The coverage analysis indicates/confirms the following:

- Indoor MFCN signal levels are not high enough to trigger the WAS/RLAN EDT across the vast majority of indoor areas. For the two MFCN BS *e.i.r.p.* levels considered, 74 dBm/100 MHz and 80 dBm/100 MHz, predicted signal levels across ~99% of indoor locations and across ~92% of indoor locations were less than the EDT, respectively. WAS/RLAN at such locations would continue to transmit;
- For the two MFCN BS *e.i.r.p.* levels considered, 74 dBm/100 MHz and 80 dBm/100 MHz, MFCN signal levels across 50% and 64% of indoor areas, respectively, are above the noise floor of WAS/RLAN receivers (-91 dBm/20 MHz) and would therefore result in MFCN to WAS/RLAN interference;

- Reducing MFCN BS *e.i.r.p.* from 80 dBm/100 MHz to 74/100 MHz dBm reduces indoor MFCN coverage over the area by 14% assuming an SNR of 0 dB. For an SNR of 5 dB indoor coverage over the area reduces by around 18%. This confirms MFCN indoor coverage is sensitive to MFCN BS power levels.

4.15.5 Conclusions

Generally, the results indicate that under the assumptions of this study there would be interference between the two types of systems. The EDT of WAS/RLAN would neither prohibit the risk of interference to MFCN, nor ensure that WAS/RLAN only operates in interference-free conditions; hence both systems may be affected.

The coverage prediction indicates that MFCN indoor signals would be below the MFCN UE noise level in 50% and 36% of the locations for an MFCN BS *e.i.r.p.* of 74 dBm/100 MHz and 80 dBm/100 MHz, respectively. The signal level predictions are conducted at ground level with relatively high levels of building penetration and can therefore be considered pessimistic for this area/study with many high buildings resulting in vertically distributed MFCN users being able to receive higher signal levels than those shown in Figure 11 and correspondingly any WAS/RLAN deployment in these areas experiencing higher interference levels.

Reducing MFCN BS *e.i.r.p.* would result in lower indoor MFCN coverage and reduce the interference from MFCN DL to WAS/RLAN but would not reduce interference from indoor WAS/RLAN to indoor and outdoor MFCN UEs. It should be noted these interference levels would be greater for buildings with lower losses.

Any reduction in MFCN BS *e.i.r.p.* would also not reduce potential interference levels from WAS/RLAN devices to uplink MFCN BS receivers and would reduce the area which EDT is triggered from MFCN BS transmissions further increasing the potential levels of interference from WAS/RLAN devices to uplink MFCN BS receivers. Again, it should be noted these interference levels would be greater for buildings with lower losses (or any opening of windows) and/or taller buildings with more direct line-of-sight paths to the MFCN BS.

4.16 STUDY C11: IMPACT OF BS *E.I.R.P.* REDUCTION ON MFCN COVERAGE AND CAPACITY

4.16.1 Introduction

This study investigated the impact of BS *e.i.r.p.* reduction from 82 dBm/100 MHz which is considered as a reference value for Upper 6 GHz in this study. It calculated coverage and throughput reduction, including average cell throughput and experienced user data rate.

4.16.2 Technical parameters

Selected parameters in line with those in section 2:

- MFCN bands/channels considered: indoor and outdoor UEs;
- UE percentage split between indoor/outdoor: 70-30;
- MFCN BS *e.i.r.p.* levels: 57 dBm/100 MHz, 72 dBm/100 MHz and 82 dBm/100 MHz;
- Urban environment with MFCN application delivered from a macro BS;
- Propagation models:
 - ETSI TR 138.901 UMa model [13], and Recommendation ITU-R P.452-17 [11] with urban clutter from Recommendation ITU-R P.2108-1 [12];
 - BEL from Recommendation ITU-R P.2109-2 [3].
- Simulation area: 7 tri-sector sites, 21 cells (hexagons), without wrap-around;
- UE height: 1.5 m for coverage calculations; indoor UEs distributed across floors for capacity calculations.

Extended Parameters:

- Inter site distance: 300 m (38 BS/km²) and 500 m (14 BS/km²);
- Number of UEs: 1050;
- MFCN loading factor: the study modelled a range of loading factors between 20% and 80%. The same network load is assumed over all cells in a simulation;
- RSRP threshold for coverage of -112 dBm/30 kHz;

- BS antenna height: 18 m used in coverage calculation, 25 m used in capacity simulation;
- UE antenna gain: 0 dB;
- UE body loss: 0 dB;
- UE antenna receive chains in capacity calculations: 4 RX;
- Scan loss for coverage: 0 dB (i.e. assuming the antenna gain is constant regardless of steering angle);
- Shadow fading not considered for coverage calculations.

Extended Methods:

- Throughput calculation: Simulating UMa propagation channel (frequency-selective channel with multiple paths and delays), assuming UE with 4 RX and 70% TDD DL factor (DDDSU), SU-MIMO, perfect channel estimation, with singular value decomposition beamforming;
- Scheduling: Proportional fair frequency selective scheduler, with up to 5 UEs sharing the resources per time slot per cell;
- FTP traffic model 1 (typical for large file transfers: software updates, data backups, etc.) making the throughput estimates not directly comparable with Report ITU-R M.2412 [35];
- BS assignment to a UE: UEs are static and are connected to the BS providing the highest RSRP.

4.16.3 Methodology

The MFCN network is modelled with 7 tri-sector sites, 21 cells. For a given environment and cell deployment (UMa with ISD 500 metres and 300 metres) the UEs appear on the network with a fixed arrival rate (in UE/cell/second) set for each simulation and they disappear after downloading a file of size 2 MB (FTP traffic model 1). Assuming UMa regardless of ISD, the BS antennas are assumed above rooftops. The antenna characteristics remain the same for both ISDs, with a mechanical tilt of 10°. For each configuration, the target arrival rate is fixed in order to reach an average resource usage between 50% and 80% (targets 50%, 80%). The observed metrics are:

- User throughput: data rate per user at a given position within the cell. Amount of a UE received data divided by the reception duration
- Average Cell throughput: Total data-rate achieved by users within the cell. Total received bits in a cell/simulation duration
- Cell edge user throughput or 5th percentile of achieved UE throughput, i.e. 95% users in the cell having a data rate greater than the cell edge user throughput. Note that cell edge user throughput corresponds to the actual user experienced data rate as stated in Report ITU-R M.2410 [34] defining Key Performance Indicators of IMT-2020 (5G).

4.16.4 Results and implications on WAS/RLAN and MFCN

Coverage impact - Reducing the *e.i.r.p.* reduces coverage as follows:

- Cell edge coverage:
 - Reducing the *e.i.r.p.* from 82 to 72 dBm/ 100 MHz lowers the probability of indoor coverage from 80% to 50%;
 - Reducing the *e.i.r.p.* from 82 to 57 dBm/ 100 MHz lowers the probability of indoor coverage from 80% to 10%.

Throughput impact - reducing the *e.i.r.p.* significantly impacts the throughput:

- Average cell throughput:
 - Reducing the *e.i.r.p.* from 82 to 72 dBm/ 100 MHz drops the throughput from 430 to 296 Mbps, i.e. a 31% throughput reduction;
 - Reducing the *e.i.r.p.* from 82 to 57 dBm/ 100 MHz drops the throughput from 430 to 95 Mbps totalling a 78% throughput reduction.
- Cell-edge user throughput:
 - Reducing the *e.i.r.p.* from 82 to 72 dBm/ 100 MHz drops the throughput from 171 to 77 Mbps, i.e. a 55% throughput reduction;

- Reducing the *e.i.r.p.* from 82 to 57 dBm/ 100 MHz drops the throughput from 171 to 7.9 Mbps totalling a 95% cell-edge user throughput reduction.

4.16.5 Conclusions

The study, addressing downlink and assuming uplink coverage is provided, assuming an RSRP threshold of -112 dBm for downlink coverage and a throughput calculation method that is based on MIMO and 3GPP UMa channel modelling, concludes that reducing the BS *e.i.r.p.* presents a coverage and capacity degradation to MFCN. Coverage likelihood for cell-edge users (assuming all are at 1.5 m above ground and in NLOS conditions) decrease by 55% for a 10 dB BS power reduction from 82 dBm/100 MHz, and by 95% when reducing to 57 dBm/100 MHz. Cell average throughput (considering indoor and outdoor users) degradation is 31% (comparing 72 dBm/100 MHz with respect to 82 dBm/100 MHz), and 78% (when reducing to 57 dBm/100 MHz from 82 dBm/100 MHz).

4.16.6 Opportunities for further studies

The study did not provide coverage and capacity metrics breakdown by indoor/outdoor users.

4.17 STUDY C6: INTERFERENCE FROM MFCN DOWNLINK TO INDOOR WAS/RLAN DEPLOYMENTS

4.17.1 Introduction

This study presents a set of simulation results to evaluate the footprint of the interference from MFCN Downlink to indoor WAS/RLAN deployments, assuming no sharing mechanism is in place.

The goal of these simulations is to provide an alignment assessment of the interference footprint in the case in which MFCN and WAS/RLAN are deployed in the same geographical area.

4.17.2 Technical parameters

This section describes the simulation assumptions used to generate the results presented in the next section.

**Table 24: Parameters used in the coexistence simulations:
Base Station (AAS), Mobile Station (UE)**

Parameter	Base station (AAS)	Mobile station (UE)
Carrier Frequency	6475-7075 MHz	
Duplex Method	TDD	
Channel bandwidth	100 MHz	
Maximum / typical output power	See Table 26	23 dBm
Noise Figure	6 dB (Wide Area BS)	9 dB
Antenna Height	See Table 26	1.5 m

**Table 25: Parameters used in the coexistence simulations:
MFCN deployment parameters, urban macro**

MFCN Deployment Parameter	Urban Macro
Deployment Layout	Hexagonal Cell, 19 Cells, 57 BSs (Note 1)

MFCN Deployment Parameter	Urban Macro
ISD	588 m
Sectorisation	3 sectors per cell
Frequency reuse	1
TDD / FDD	TDD
UE Indoor/Outdoor Probability	30/70%
BS TDD activity factor	75%
Note 1: "1 BS" = 1 sector in 3-sector cell.	

**Table 26: Parameters used in the Coexistence Simulations:
MFCN Base Station parameters, urban macro**

MFCN Base Station Parameters	Urban Macro
Antenna height	18 m
Antenna pattern	Refer to Recommendation ITU-R M.2101 [4]
Element gain (dBi) (Note 1)	5.5
Horizontal/vertical 3 dB beamwidth of single element (degree)	90° for H 90° for V
Horizontal/vertical front-to-back ratio (dB)	30 for both H/V
Antenna polarisation	Linear $\pm 45^\circ$
Antenna array configuration (Row \times Column) (Note 2)	Antenna Array Size #1: 16 \times 8 elements Antenna Array Size #2: 32 \times 16 elements (Note 8)
Horizontal/Vertical radiating element spacing	0.5 of wavelength for H, 0.5 of wavelength for V
Array Ohmic loss (dB) (Note 1)	2
Conducted power (before Ohmic loss) per antenna element (dBm) (Note 6)	22 (for 16x8 Antenna Array) 10 (for 32x16 Antenna Array) (Note 5, Note 8)
Base station maximum coverage angle in the horizontal plane (degrees)	± 60
Base station vertical coverage range (degrees) (Notes 3, 4, 7)	90-120
Mechanical downtilt (degrees) (Note 4)	10
<p>Note 1: The element gain includes the array ohmic loss. This means that the parameter "array ohmic loss" is not needed for the calculation of the BS composite antenna gain and e.i.r.p.</p> <p>Note 2: Row \times Column means there are Row vertical and Column horizontal radiating elements,</p> <p>Note 3: The vertical coverage range is given in global coordinate system, i.e. 90° being at the horizon.</p> <p>Note 4: The vertical coverage range includes the mechanical downtilt.</p> <p>Note 5: The conducted power per element assumes 8 \times 8 \times 2 and 32 \times 16 \times 2 elements, respectively, (i.e. power per H/V polarized element).</p> <p>Note 6: In sharing studies, the transmit power calculated using the conducted power (before Ohmic loss) per antenna element is applied to the bandwidth given in Table 26.</p> <p>Note 7: In sharing studies, the UEs that are below the coverage range can be considered to be served by the "lower" bound of the electrical beam, i.e. beam steered towards the max. coverage angle. A minimum BS-UE distance along the ground of 35 m should be used for urban macro.</p>	

MFCN Base Station Parameters	Urban Macro
Note 8: The configuration for the 32x16 Antenna Array is derived assuming a larger number of antenna elements and scaled conducted power accordingly, i.e. the same e.i.r.p.as the configuration for the 16x8 Antenna Array.	

Table 27: Parameters used in the Coexistence Simulations: WAS/RLAN parameters

WAS/RLAN Parameter	WAS/RLAN Device (AP)	Comments
Carrier Frequency	6475-7075 MHz	Same as MFCN
Devices Deployment	100% Indoor	For the purposes of this analysis, indoor deployments only are considered.
Antenna/Building Height	Probability distribution according to ECC Report 302 [6] for Urban Indoor/Home	
Antenna Model	Isotropic Antenna Model	

4.17.3 Study methodology

The methodology is based on the following assumptions: MFCN utilises 3GPP RAT licensed technology, with no band-specific additional restrictions on macro BS transmitted power. WAS/RLAN operates (mainly) indoor deployments, focusing on LPI WAS/RLAN. No coexistence mechanism is assumed to be in place.

The approach used in the simulations is based on the Monte Carlo method, according to which interference results for multiple independent realisations (also called snapshots) of MFCN UE placement in the deployment area, UE scheduling, BS beam orientation and WAS/RLAN AP locations are collected and then processed to infer their statistical properties.

Full buffer scheduling is assumed in the study without TDD activity factor.

The approach used in the simulations is based on the Monte Carlo method, according to which interference results for multiple independent realisations (also called snapshots) of MFCN UE locations in the deployment, UE scheduling, BS beam orientation and WAS/RLAN AP locations are collected and then processed to infer their statistical properties. The number of realisations used to generate the results included in this study is 10000.

Figure 12 portrays a single realisation of the Monte Carlo-based approach used to generate the CDF showed in the simulation results section. The random MFCN deployment drop shows 19 hexagonal cells (red X) and 57 sectors (the orientation is shown with blue arrows).

The randomly dropped UEs are marked with black dots, and the served UE for each sector is circled in magenta (scheduling is based on coupling loss metrics). When multiple UEs ($N_{UE}=3$) are scheduled per each sector, the MFCN BS power is equally split between the beams pointing at the 3 users.

In the example below, randomly dropped WAS/RLAN deployments are identified with green squares marking the location of the AP. In the case of co-located WAS/RLAN and MFCN deployments, the location of the served MFCN UEs always coincides with the location of the dropped AP, but the deployment height is independent (according to the random modelling) to model the usage on different floors within the same building.

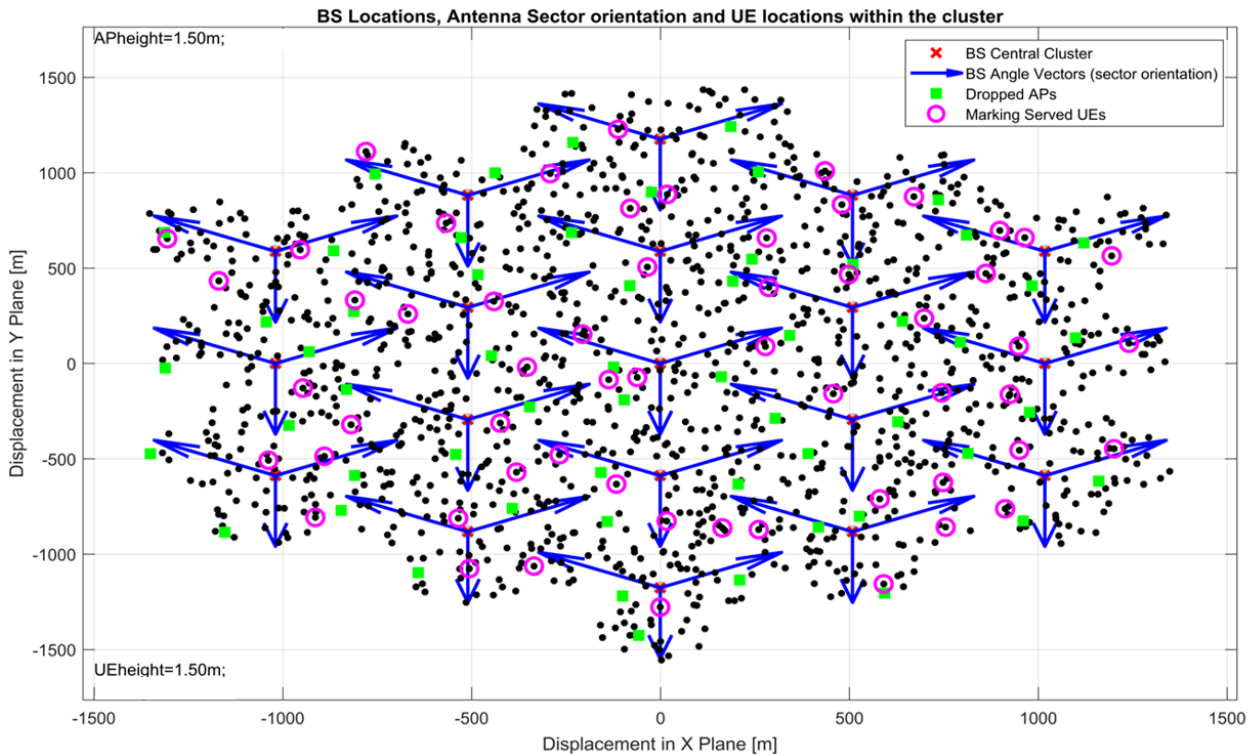


Figure 12: Snapshot of a single Monte Carlo realisation, random deployment

The path loss between MFCN BS and MFCN UE/RLAN AP for LOS/NLOS paths follows the 3GPP Urban Macro model, according to ETSI TR 138.901 v16.1.0 [13]. Small scale fading is not considered in these simulations. The Building Entry Loss (BEL, or Indoor Penetration) follows the Recommendation ITU-R P.2109-1 [3], assuming a typical distribution of 70% traditional and 30% thermally efficient buildings. The result plots include, for reference only, the thermal noise power (green dashed line) at room temperature (300 K) for the 100 MHz bandwidth assumed, computed according to the following equation:

$$P_N = -173.8 \text{ dBm} + 10 \cdot \log_{10}(100 \cdot 10^6 \text{ Hz}) \cong -94 \text{ dBm}$$

4.17.4 Results and implications for WAS/RLAN and MFCN

The simulation results show the CDF of the total interference power observed at the WAS/RLAN AP for the scenarios below.

4.17.4.1 Single scheduled MFCN UE in a sector

For this case the study shows a comparison between the interference at the WAS/RLAN AP for these two scenarios:

- a) when the WAS/RLAN AP and served MFCN UE locations are random and uncorrelated (solid lines), and
- b) the “worst-case scenario” when the WAS/RLAN AP is always co-located in the same building as the scheduled MFCN UE (dashed lines). In this scenario, APs and UEs are randomly placed in different floors within the same building;

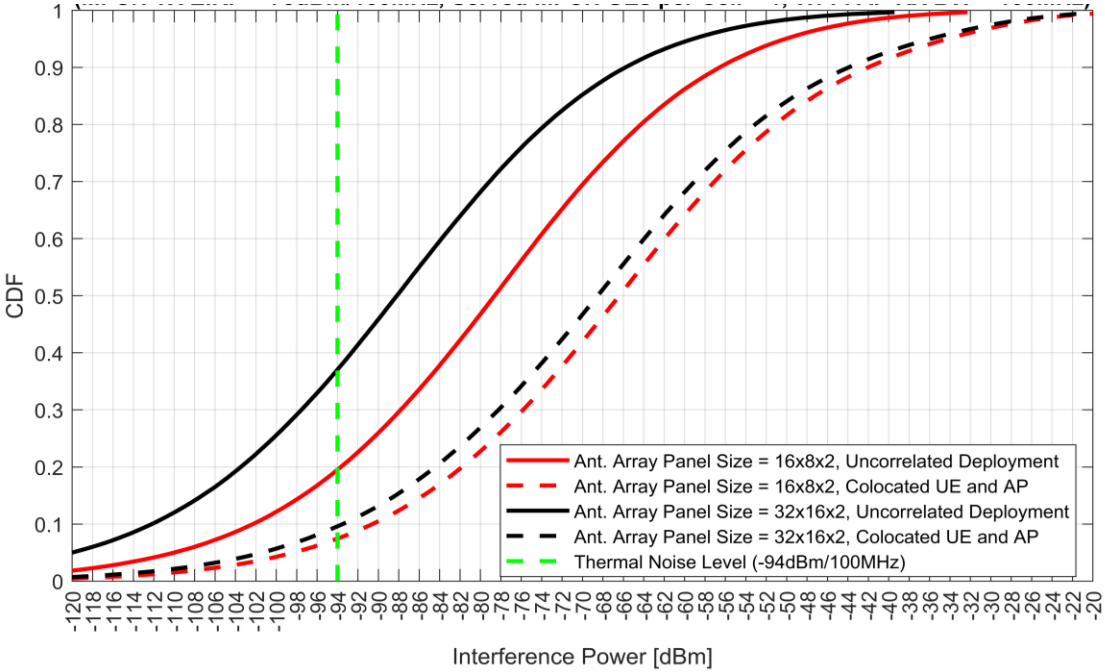


Figure 13: Interference power CDF at WAS/RLAN AP RX from MFCN BS DL, random vs co-located deployment (MFCN TX e.i.r.p.= 73 dBm/100 MHz, served MFCN UEs per cell = 1, WAS/RLAN AP RX BW = 100 MHz)

In the random and uncorrelated case, the AAS used at the MFCN BS is able to create less interference to the WAS/RLAN deployment, through the use of more selective (narrower) beams to serve its scheduled user. When the deployments are co-located, the increase in interference power can be noticed.

4.17.4.2 Three simultaneously scheduled MFCN UEs in a sector

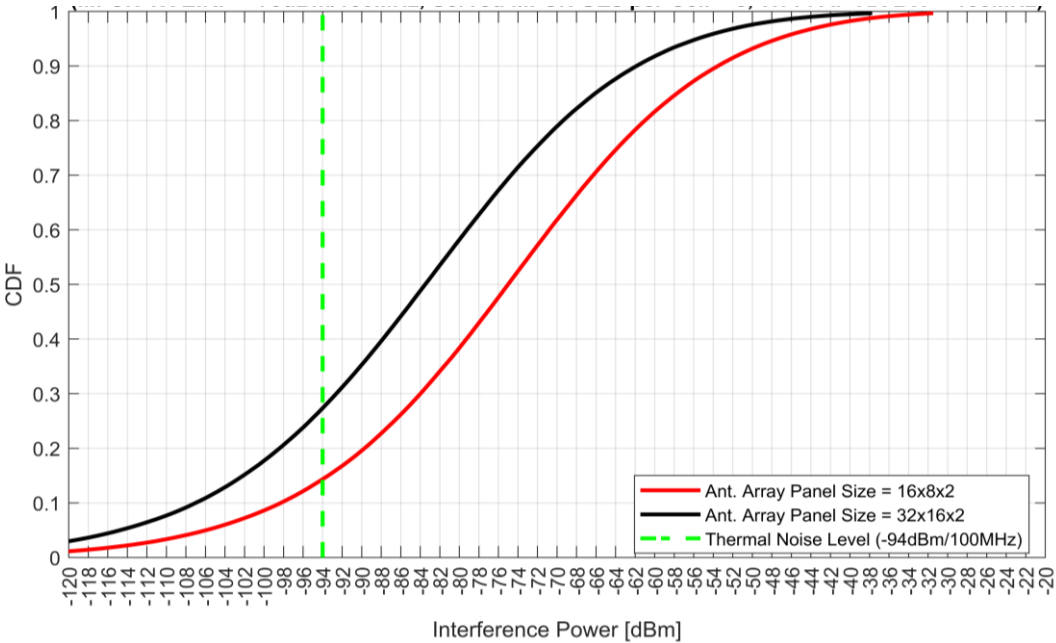


Figure 14: Interference power CDF at WAS/RLAN AP RX from MFCN BS DL (MFCN TX e.i.r.p.= 73 dBm/100 MHz, served MFCN UEs per cell = 3, WAS/RLAN AP RX BW = 100 MHz)

When the total *e.i.r.p.* is split into 3 beams pointing at different users, the more distributed energy results in both a narrower CDF (less variation in space compared to using a single beam) and an increase in the median value.

4.17.5 Conclusions

Based on the assumptions used in the study, and assuming no mitigation measures, WAS/RLAN APs are expected to receive a level of interference from MFCN BS operating in DL with 73 dBm *e.i.r.p.* above the Noise Floor with a probability between 60-90% of the cases observed. The amount of interference can be reduced using a larger AAS panel size at the MFCN BS, and its statistical properties depend on the correlation between scheduled UE and WAS/RLAN deployment.

4.17.6 Opportunities for further studies

In these studies, two different coexistence scenarios have been investigated, for uncorrelated and correlated active deployments. In the general framework of Monte Carlo simulation with uncorrelated deployment location, the measured performance is obtained by averaging across multiple UEs randomly distributed within the coverage area.

In the case of non-overlapping WAS/RLAN and NR deployments, the performance for a single user averaged in the time domain is expected to be in line with the performance averaged across multiple users in the spatial domain.

On the other hand, in the case of overlapping deployments, the users experience a very different impact depending on their relative location compared to the interferer. As a consequence, the average performance in the time domain for co-located users would largely differ from the UE performance averaged across all locations. The average activity factor of WAS/RLANs is not sufficient to fully characterise the potential interference impact from WAS/RLANs to MFCN UEs when co-located. The study examines the interference from WAS/RLANs co-located to MFCN UEs assuming active WAS/RLAN transmissions. This corresponds to a worst-case analysis as in practice WAS/RLANs do not transmit continuously and MFCN UEs do not receive continuously. Further studies could be carried out to assess the impact of coexistence in the co-located scenario taking into account time domain aspects (e.g. activity factor and time-frequency resources allocation).

4.18 STUDY C7: WAS/RLAN COVERAGE AND CAPACITY UNDER HIGH MFCN BS E.I.R.P.

4.18.1 Introduction

The study considers shared use of spectrum aiming at WAS/RLAN operating indoor and MFCN operating outdoor.

The throughput figures in this study for the WAS/RLAN case are defined as the aggregate instantaneous throughput over 7 instantly transmitting WAS/RLANs links assuming fixed path-loss corresponding to a 9 m AP-STA distance, averaged over the 300 m MFCN cell range.

4.18.2 Technical parameters

The study considers an MFCN deployment following assumptions in section 2. It considers 7 indoor LPI WAS/RLANs in an MFCN sector, corresponding to a population density of around 5600 habitants per km² (e.g. Copenhagen city centre).

The study considers the alternative parameters in Table 28.

Table 28: Parameters used in the study

Assumption	Common assumptions	Study
MFCN Base station TX power	Several	67 dBm/80 MHz <i>e.i.r.p.</i> to 87 dBm/80 MHz <i>e.i.r.p.</i>
WAS/RLAN Bandwidth	20 MHz (10%), 40 MHz (5%), 80 MHz (30%), 160 MHz (35%), 320 MHz (20%)	80 MHz (100%) WAS/RLAN and MFCN channel overlapping 100%
WAS/RLAN height	Distribution	1.5 m

4.18.3 Study methodology

The study assesses the percentage of indoor locations where the WAS/RLAN EDT is triggered. In this study, it is considered that a WAS/RLAN can operate in a specific indoor location if the MFCN DL signal is below the WAS/RLAN EDT. When the MFCN DL signal level is below the WAS/RLAN EDT, the WAS/RLAN throughput is derived taking into account the interference from the MFCN DL.

The study does not take into account the time domain, MFCN frame format, WAS/RLAN channel access mechanisms, MFCN cell load, MFCN and WAS/RLAN activity factors, channel adaptation and retransmission mechanisms. The simulation also assumes that a WAS/RLAN receiving the MFCN DL signal above the EDT on average would vacate the channel.

4.18.4 Results and implications for WAS/RLAN and MFCN

4.18.4.1 Considerations on location

- Locations of overlap where both WAS/RLAN and MFCN would be deployed: in urban areas, MFCN BS would reuse MFCN 3.5 GHz cell sites, while WAS/RLAN LPI would aim at indoor connectivity;
- Locations where only MFCN would be deployed: not considered in this study;
- Locations where only WAS/RLAN would be deployed: not considered in this study.

4.18.4.2 Main results

The study derives the percentage of indoor locations where WAS/RLAN can operate, i.e. the percentage of locations where the WAS/RLAN EDT is not triggered. The reduction of the percentage of indoor locations where WAS/RLAN can operate is provided in Figure 15.

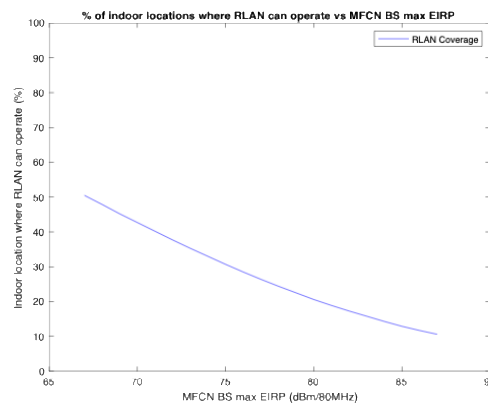


Figure 15: Percentage of locations where LPI WAS/RLAN AP can operate vs MFCN BS max. e.i.r.p.

Even where WAS/RLAN can operate, the WAS/RLAN SINR is likely to be reduced by interference from the MFCN. The WAS/RLAN throughput vs the MFCN BS *e.i.r.p.* is provided in Figure 16.

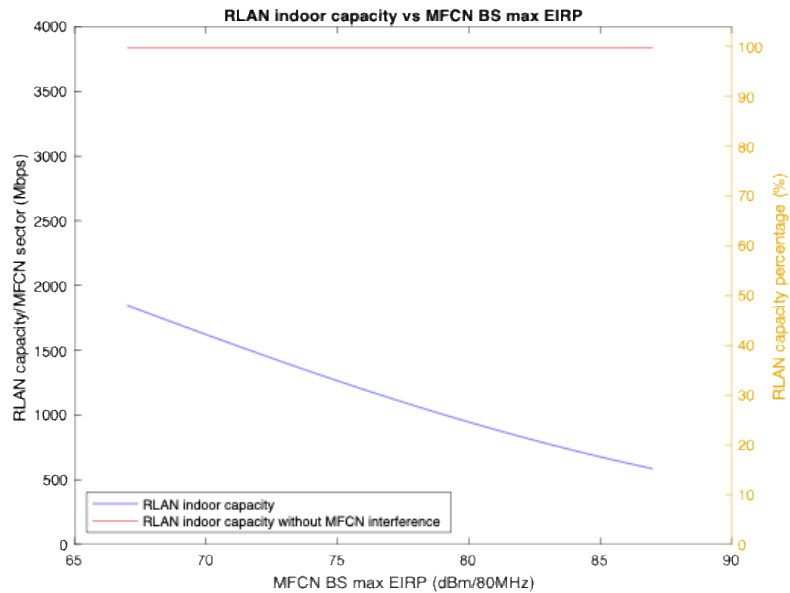


Figure 16: Throughput of 7 WAS/RLANs vs MFCN BS max. *e.i.r.p.*

4.18.5 Discussion on benefit/drawbacks of studied sharing scenario

Concurrent WAS/RLAN indoor and MFCN outdoor deployment provides benefits to both systems in dense urban areas, i.e. where both systems spectrum needs are the highest. Shared use of spectrum aiming at WAS/RLAN indoor and MFCN outdoor is unlikely to provide benefits if MFCN BS *e.i.r.p.* is at or above 67 dBm/80 MHz.

Degradation of WAS/RLAN spectrum access and throughput would increase the percentage of traffic delivered by mobile network. Every bit delivered over the mobile network requires 10x the energy of a bit delivered over the fibre/WAS/RLAN network, degrading the digital sustainability [36].

4.18.6 Conclusions

The study highlights the incompatibility between MFCN deployment leveraging BS *e.i.r.p.* above 67 dBm/80 MHz and WAS/RLAN indoor.

Overall, the study indicates that:

- if MFCN operates at *e.i.r.p.* of 67 dBm/80 MHz (respectively 87 dBm/80 MHz), it is not possible to enable shared use aiming at MFCN outdoor and WAS/RLAN indoor. In particular, WAS/RLAN would not be able to operate in 50% (respectively 90%) of the indoor locations due to MFCN DL signal exceeding the WAS/RLAN EDT;
- limiting the reduction of indoor locations where WAS/RLAN can operate and the impact on throughput of indoor WAS/RLAN operating co-channel with outdoor MFCN would require a range of MFCN *e.i.r.p.* well below 67dBm/80 MHz (see study B3 in section 4.10).

4.18.7 Opportunities for further studies

The study only assesses the overall throughput and does not estimate the impact on other QoS metrics such as latency and reliability.

Should there be an interest in leveraging the LBT WAS/RLAN mechanism to improve coexistence between WAS/RLAN indoor and MFCN outdoor, further studies are required to ensure that WAS/RLAN APs detecting an MFCN DL signal above the EDT vacate the channel. Alternatively, a cross-technology signalling mechanism could be leveraged, as discussed in study B2 (see section 4.9).

4.19 STUDY C10: UPPER BOUND ON VLP WAS/RLAN INTERFERENCE TO MFCN UL AND DL

4.19.1 Introduction

The scenario considered corresponds to a shared use of the 6 GHz band in the time domain, where VLP WAS/RLANs are allowed in the band independently of MFCN deployment. As MFCN are deployed and their service cover specific locations, VLPs operating in the location could pose a potential risk of interference to the MFCN.

VLPs are typically leveraged to connect two body worn devices, for example augmented reality (AR) glasses to a smartwatch or a smartphone. The VLP link is leveraged for instance to render AR images on a remote device so to limit the processing requirements on the AR glasses. An AR processing link needs to be high data rate, low latency and low power, but does not require wide area connectivity. VLP WAS/RLANs are uniquely positioned for such innovative use cases around Personal Area Network connectivity. The remote processing unit (smartwatch, smartphone, PC) may or may not be connected to the internet through WAS/RLAN, fibre/ethernet or cellular connectivity.

VLP WAS/RLANs transmit at 14 dBm, leading to a lower risk of interference than LPI. The study estimates the interference level caused by VLP devices to MFCN, on both uplink (UL) and downlink (DL), under the following worst-case operational assumptions:

- VLPs always transmit at maximum power;
- VLP channels fully overlap with MFCN channel;
- most sensitive MFCN BS and UEs;
- there is no consideration of VLP's Listen Before Talk, i.e. VLPs are transmitting irrespective of the interference they receive from MFCN;
- the study considers both VLP Activity Factor of 1.97% and 20% (sensitivity analysis);
- these assumptions are pessimistic, in particular the assumptions that all VLPs remain on the MFCN channel. Population densities as high as 15000 habitants per km² are also rare in Europe.

4.19.2 Technical parameters

The population density assumed is 15000 habitants/km², corresponding to a dense urban area. Under Scenario A of Table 10 assumptions, 50 VLPs of bandwidth 80 MHz and 100 VLPs of bandwidth 160 MHz VLPs are considered in the 5 km² simulated area. Both indoor and outdoor VLPs are considered. With activity factors of 1.97% and 20%, this implies that, on average, at any instant in time there are a total of 1 and 10 VLPs of bandwidth 80 MHz, and 2 and 20 VLPs of bandwidth 160 MHz, in the 5 km² area being accounted for in the calculation of interference towards the MFCN BS and UEs in the central cell.

Indoor VLPs and UEs are considered in the same room if they are both located indoor, and less than 10 m from each other on the same floor. Based on the assumptions, UE and VLP are almost never in the same room. Note that this does not suggest that MFCN UEs and VLPs would not operate in the same room, but simply indicate that given the number of active devices, the probability that they are active at the same time in the same room is very low.

Effects due to multiple VLP transmissions in time within the duration of MFCN radio packets are not addressed in this study.

A 9 dB Noise Figure is assumed for VLPs.

MFCN is assumed to operate on 100 MHz with a MFCN BS *e.i.r.p.* of 70 dBm/100 MHz. For simplicity, VLPs are assumed to fully overlap with the MFCN channel. Both indoor and outdoor MFCN UEs are considered. The most selective sensitivity values (6 dB for BS, 9 dB for UE) are assumed, corresponding to a worst-case.

Propagation model Option 1 (Recommendation ITU-R P.1411-12 [9]) is selected, as well as building entry loss Option 1 (Recommendation ITU-R P.2109-2 [3] with 70% 'Traditional' and 30% 'Thermally-efficient' buildings, with a uniformly distributed probability from 1% to 99%).

4.19.3 Study methodology

The Monte-Carlo simulation considers a 7 cell (21 sectors) MFCN deployment, inside a 2.320 km East-West and 2.160 km North-South simulation area. 50 VLPs with 80 MHz bandwidth and 100 VLPs with 160 MHz bandwidth are dropped randomly in the area, as well as 3 UEs per sector. Each VLP is then modelled to be active based on probabilities of 1.97% and 20%. The MFCN beams are derived to point towards the served UE. All variable parameters are determined according to their distribution. The MFCN signal strength is derived from each BS beam to each UE (and vice-versa). The WAS/RLAN interfering signal to each beam and each UE is derived. The interference from BS beams to WAS/RLANs and UEs to WAS/RLANs are derived.

Finally, the SINR is derived for each device.

4.19.4 Results and implications for WAS/RLAN and MFCN

On the downlink, VLP WAS/RLANs do not lead to any degradation of the MFCN UE SINR, even under worst-case assumptions.

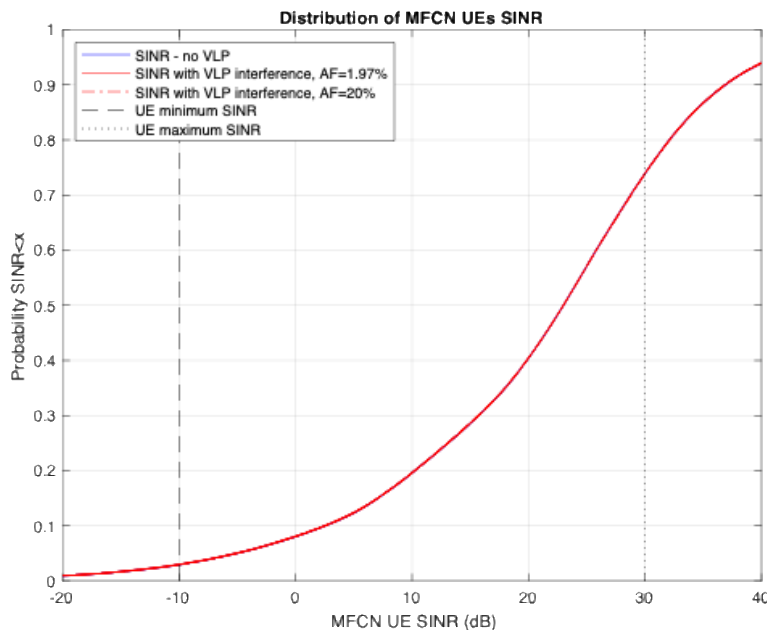


Figure 17: SINR at MFCN UE

The analysis is robust for both indoor and outdoor MFCN UEs, i.e. no degradation of performance is expected in the downlink.

VLPs do not significantly degrade the MFCN UL throughput per UE. A sensitivity analysis assuming an unrealistic activity factor of 20% for all VLPs in the simulated area triggers a degradation of the MFCN UL throughput by approximately 2 Mbps.

However, it should be noted that close to 50% of the indoor UEs achieve a throughput lower than 20 Mbps, assuming constant UL transmission. No UE can achieve better than 50 Mbps in UL.

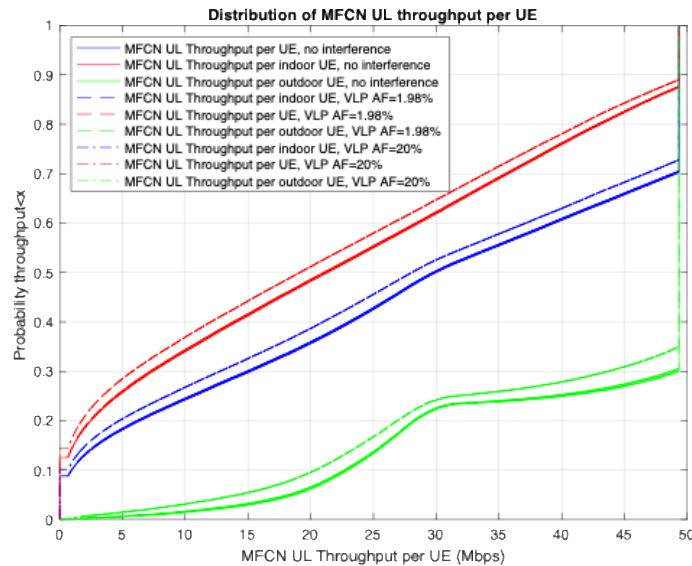


Figure 18: MFCN UL throughput for all UEs, indoor UEs and outdoor UEs, with and without worst-case VLP interference

4.19.5 Conclusions

The study demonstrates that VLP WAS/RLAN would not create any interference to either MFCN DL or UL for a VLP activity factor of 1.97%. For a VLP activity factor of 20%, there is still no interference to MFCN DL, although there is some interference to MFCN UL.

There is no need for any additional sharing mechanism, as the low transmit power of VLP WAS/RLAN ensures that they do not interfere with MFCN DL or UL. Even under significant worst-case sensitivity analysis (all VLPs remain on MFCN channel, all VLPs have an Activity Factor of 20%, all VLPs transmit at maximum power) the degradation of the MFCN UL is not substantial (there is no impact on the MFCN DL, while the throughput impact on MFCN UL would not exceed 2 Mbps). This study did not consider a co-located deployment where VLP devices are active in close proximity to the MFCN UEs.

4.20 STUDY A5: IMPACT OF MFCN COVERAGE ENHANCEMENT TECHNIQUES ON THE MFCN SINR AND INTERFERENCE TO WAS/RLAN

4.20.1 Introduction

Some studies have proposed that MFCN BS *e.i.r.p.* power levels of 50-60 dBm/100 MHz might facilitate co-channel sharing between MFCN and indoor WAS/RLANs in the Upper 6 GHz. A reduction in MFCN BS *e.i.r.p.* would result in a proportional reduction of co-channel interference from MFCN BSs to indoor WAS/RLANs. However, the proposed reductions down to 50-60 dBm/100 MHz would also affect the provision of coverage/capacity by MFCN in the Upper 6 GHz, both outdoors (with some studies showing degradation and others not) and indoors.

This study further investigates the implications of a denser MFCN deployment associated with reduced *e.i.r.p.* levels. Notably, the *e.i.r.p.* levels of BSs deployed in the 3.5 GHz band in Europe are typically around 75-78 dBm. This is consistent with the 3.5 GHz band license conditions in many countries in Europe [1] which allow *e.i.r.p.* levels of up to 82 dBm/100 MHz but different from the assumptions of 73 dBm/100 MHz for WRC-23 studies. Therefore, the proposed reduced levels of 50-60 dBm/100 MHz would lead to a significant reduction of up to 32 dB compared with some deployments in the 3.5 GHz band and about 15 dB compared to the assumptions for WRC-23. If city-wide MFCN coverage in the Upper 6 GHz band was targeted, then delivery with 50-60 dBm/100 MHz *e.i.r.p.* would require densification of the network.

The study investigates the following two scenarios:

- 1 **Scenario (1)** – Mobile network operators would deploy MFCN with the proposed reduced BS *e.i.r.p.* levels on an MFCN grid with a 450 m ISD.
- 2 **Scenario (2)** – Mobile network operators would deploy MFCN with the proposed reduced BS *e.i.r.p.* levels on a denser MFCN grid (ISDs of 225 and 159 m) with the goal to achieve indoor coverage. This approach would aim to raise the received MFCN signal power levels back to the values which would be experienced through the use of full power MFCN BSs. Inevitably, this would also raise the levels of interference to WAS/RLAN and impact the shared use of the band.

This study quantitatively demonstrates the drawbacks of reduced MFCN BS *e.i.r.p.* by specifically examining the option of network densification, i.e. where mobile network operators would deploy large numbers of BSs across cities and towns

This study presents the signal-to-interference-plus-noise ratio (SINR) experienced on the MFCN downlink throughout the cell, as well as the corresponding levels of total received over-the-air (OTA) MFCN signal power throughout the cell for Scenario (1), maintaining the same ISD of 450 m for *e.i.r.p.* levels of 82 dBm/80 MHz, 67 dBm/80 MHz and 57 dBm/80 MHz.

The study also presents the above described SINR and total received signal power for Scenario (2), whereby the geographic density of the mobile network BSs is increased by factors of $\times 4$ and $\times 8$ (ISD reduced by factors of 2 and $\sqrt{8}$ to 225 and 159 metres for *e.i.r.p.* levels of 67 dBm/80 MHz and 57 dBm/80 MHz, respectively), in order to match the downlink SINR achieved with 82 dBm/80 MHz. Although the ISDs are reduced, other associated network parameters (e.g. downtilt, antenna height etc.) were not varied.

4.20.2 Technical parameters

Unless otherwise stated, this study uses the MFCN parameter values recommended in [20] for urban macro-cellular MFCN deployments. In there a bandwidth of 100 MHz is recommended. The study assumes 80 MHz for consistency with a WAS/RLAN channel bandwidth of 80 MHz and the assessment of co-channel interference. This is not expected to have a material impact on the conclusions. In addition to the ISD of 450 metres (17 BS/km² which is different from the assumption in section 2), this study also examines ISDs of 225 and 159 metres (68 and 137 BS/km²).

In addition to the *e.i.r.p.* level of 71.6 dBm/80 MHz, this study examines *e.i.r.p.* levels of 82 dBm/80 MHz, 67 dBm/80 MHz and 57 dBm/80 MHz.

4.20.3 Study methodology

The results presented in this study are derived based on the same methodology and parameter values described in Study C3 (see section 4.12) for the calculation of received MFCN signal power levels.

4.20.4 Results and implications for WAS/RLAN and MFCN

4.20.4.1 Scenario (1)

In Scenario (1) the MFCN BS *e.i.r.p.* is reduced for a fixed ISD of 450 m. The reduction in MFCN BS *e.i.r.p.* leads to a degradation in downlink SINR. With a reduced MFCN BS *e.i.r.p.* of 57 dBm/80 MHz, the minimum required SINR of -10 dB is not achieved in 35% of indoor locations, up from around 6% for an MFCN BS *e.i.r.p.* of 82 dBm/80 MHz. This represents a 29% reduction in indoor coverage.

The reduction in MFCN BS *e.i.r.p.* would result in an equivalent reduction in the interference towards indoor WAS/RLAN. With a reduced MFCN BS *e.i.r.p.* of 57 dBm/80 MHz, the WAS/RLAN EDT would not be triggered (WAS/RLAN equipment can transmit) in 70% of indoor locations across an MFCN cell, up from around only 20% for an MFCN BS *e.i.r.p.* of 82 dBm/80 MHz.

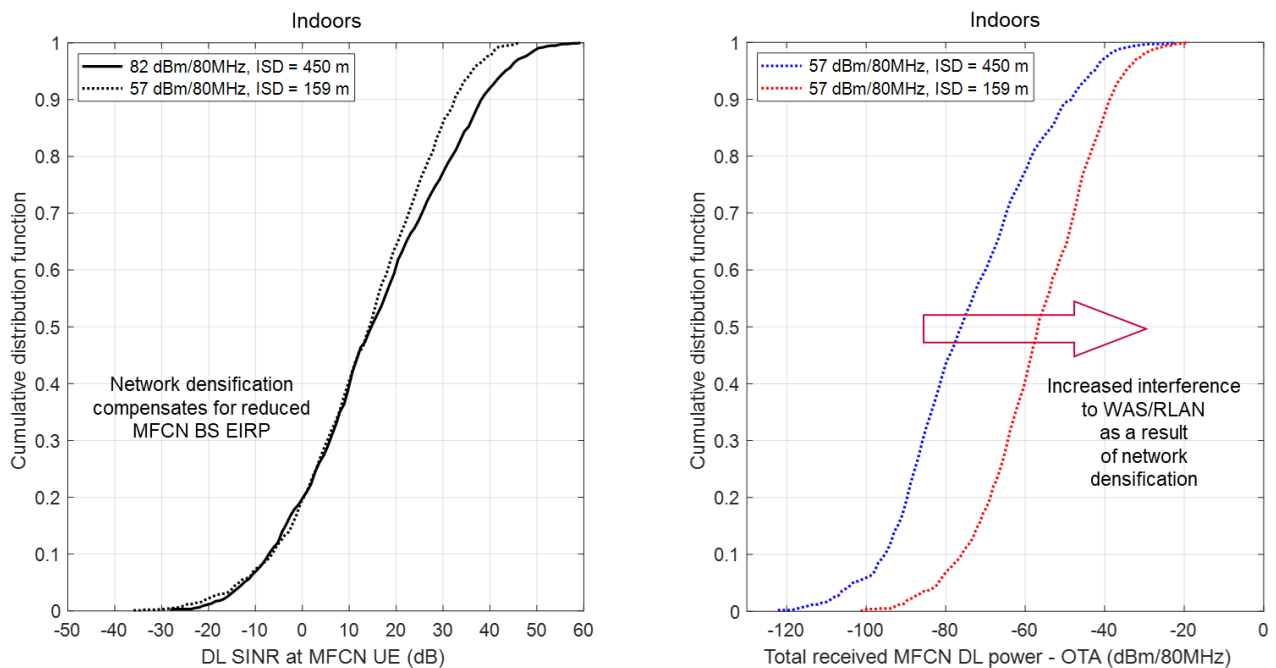
Reduced MFCN BSs *e.i.r.p.* would therefore lead to degraded services to indoor end users.

4.20.4.2 Scenario (2)

In Scenario (2) the MFCN BS *e.i.r.p.* and ISD are both reduced. As can be seen in Figure 19(a), the applied densifications with ISDs of 225 and 159 metres for BS *e.i.r.p.* levels of 67 dBm/80 MHz and 57 dBm/80 MHz would allow the operator to achieve a similar SINR as the case of 450 m ISD with an *e.i.r.p.* of 82 dBm/80 MHz. The likelihood of achieving the minimum required SINR of -10 dB would then become equal to that for the non-densified ISD of 450 metres and a BS *e.i.r.p.* of 82 dBm/80 MHz.

As can be seen in Figure 19(b), the applied densifications also increase the levels of received MFCN downlink signal power across the cell and, consequently, increase the levels of interference to WAS/RLAN, compared to Scenario (1). Despite reductions of 15 and 25 dB in MFCN BS *e.i.r.p.*, the interference to WAS/RLAN is only reduced by 3 and 6 dB, respectively, compared to a non-densified MFCN with BS *e.i.r.p.* of 82 dBm/80 MHz, and this is insufficient to enable sharing. Furthermore, the WAS/RLAN EDT would not be triggered (WAS/RLAN equipment can transmit) in 30% of indoor locations across an MFCN cell, up from around 20% for a non-densified MFCN with BS *e.i.r.p.* of 82 dBm/80 MHz. Significant MFCN signal levels would still exist across many indoor areas even where the WAS/RLAN energy detection level is not triggered, thereby impacting indoor WAS/RLAN applications in those areas.

Under Scenario (2), operators would require more BSs to serve the same amount of traffic if indoor coverage similar to that from 82 dBm/80 MHz is targeted.



(a) MFCN SINR

(b) Interference to WAS/RLAN

Figure 19: Increases in MFCN SINR and interference to WAS/RLAN as a result of MFCN densification

4.20.5 Conclusions

The results show that reduced MFCN BS *e.i.r.p.* combined with the adoption of network densification (while keeping antennas above rooftops), for the purpose of matching the coverage of an 82 dBm/80 MHz MFCN network, would to a great extent negate any reductions in interference towards WAS/RLAN brought about by the reduction in MFCN BS *e.i.r.p.* and would impact the shared use of the band.

4.20.6 Opportunities for further studies

None.

5 CONSIDERATIONS AND ANALYSES ON MFCN DOWNLINK/UPLINK AND VALIDATIONS THROUGH MFCN FIELD TRIALS

A list of links to the complete studies and field trials summarised in this section is available [here](#).

This section contains results from studies and field tests that help understanding the implication of *e.i.r.p.* levels on MFCN performance (e.g. cell edge throughput).

5.1 STUDY E1: VARIATION OF MFCN DOWNLINK THROUGHPUT AS A FUNCTION OF MFCN BASE STATION *E.I.R.P.* IN THE UPPER 6 GHZ BAND

This study quantified the impact on the level of service delivered to outdoor end users as a result of a decrease in the *e.i.r.p.* of MFCN BSs, and with other MFCN deployment parameters unchanged.

The study models full-buffer MFCN downlink emissions from a total of 7 sites in a hexagonal arrangement with three MFCN base stations (BSs), or cells, per site (i.e. a total of 21 BSs), where each BS forms a link-adapted beam from an active antenna system (16V×16H, 2 elements per vertical sub-array) towards an MFCN UE located in its cell. The BSs are at a height of 18 metres above ground, and with an inter-site distance of 450 metres (17 BS/km²) which corresponds to an MFCN cell radius of 300 metres. The study then calculates the statistics of the MFCN downlink throughput at all outdoor locations within the MFCN centre cell.

The MFCN UEs are assumed to have uniformly distributed random horizontal locations within each MFCN cell, and at a height of 1.5 metres above ground, with the UEs performing minimum mean-square error interference rejection combining (MMSE-IRC).

Radio propagation (including path loss, shadowing loss, and multipath fading) from MFCN BSs to the outdoor UEs is modelled according to ETSI TR 138 901 [13] and includes a body loss of 4 dB.

The study indicates the following conclusions with reference to the outdoor downlink throughput delivered by each MFCN BS in a 100 MHz channel in the Upper 6 GHz band operating in urban areas:

- 1 As shown in Figure 20, the average outdoor downlink throughput at locations within the MFCN cell increases with increasing MFCN BS *e.i.r.p.*, and only begins to saturate at a *e.i.r.p.* of 81 dBm/100 MHz. A decrease in *e.i.r.p.* from 81 to 70 dBm/100 MHz results in an 11% reduction in average downlink throughput within the MFCN cell, with a 22% reduction where *e.i.r.p.* is decreased to 60 dBm/100 MHz.

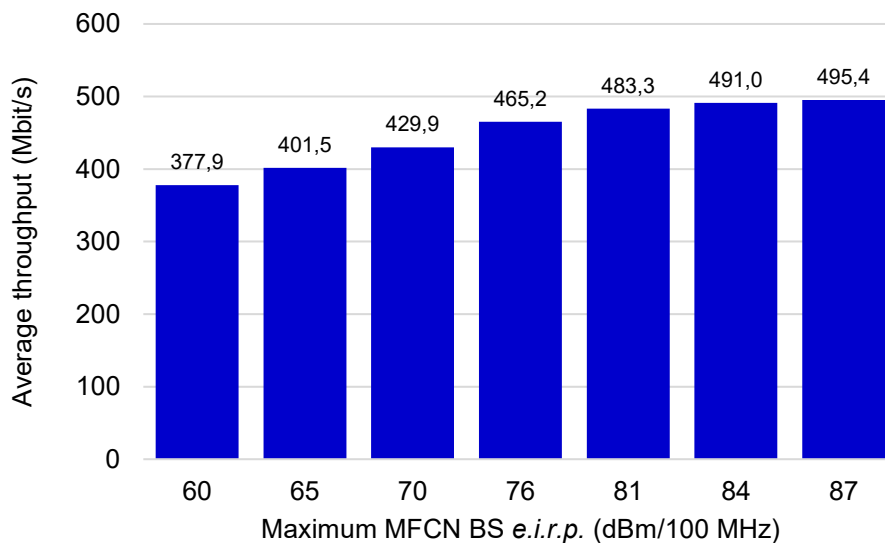


Figure 20: Average MFCN downlink throughput outdoors

- 2 Figure 21 shows the throughput results at the cell-edge (5th percentile throughput at locations within the

MFCN cell). Outdoor downlink cell-edge throughput reduces by 66% as the MFCN BS *e.i.r.p.* decreases from 81 dBm/100 MHz to 70 dBm/100 MHz, and by 99% when MFCN BS *e.i.r.p.* decreases to 60 dBm/100 MHz.

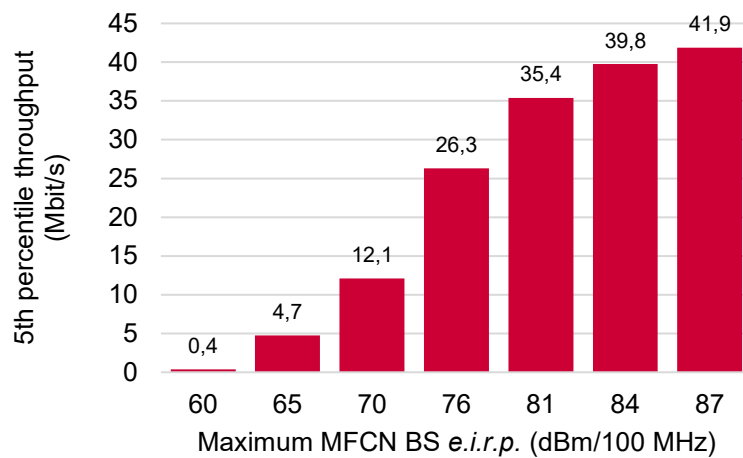


Figure 21: 5th percentile MFCN downlink throughput outdoors

Note that given the state of the art in radio technology today, the emissions from active antenna systems in the Upper 6 GHz band can be made to comply with the limits on the MFCN BS expected *e.i.r.p.* (as specified in Resolution 220 (WRC-23) of the Radio Regulations [40]) for a *e.i.r.p.* of 83 dBm/100 MHz. It is expected that this may apply to higher *e.i.r.p.* levels with future advances in technology.

5.2 6 GHZ BAND DOWNLINK AND UPLINK COVERAGE CONSIDERATIONS

5.2.1 6 GHz band uplink and downlink indoor coverage considerations

Understanding the characteristics of MFCN uplink and downlink in the Upper 6 GHz band is crucial for understanding the potential for the Upper 6 GHz band to support MFCN.

As noted in section 2, some of the studies in this Report are based on the assumption that future Upper 6 GHz MFCN deployments would re-use the existing 3.5 GHz cellular grid, based on today's equipment. It is therefore relevant to consider:

- 1 The differences in physical characteristics between the two bands, i.e. propagation etc.
- 2 Future technology and building evolution, to provide a relative comparison of the expected coverage between today's 3.5 GHz products and the expected Upper 6 GHz products to address the propagation gap.

These aspects are explored in the following sections.

It is to be noted that other studies in this Report assumed that the Upper 6 GHz deployments would be based on the need to provide additional outdoor capacity and not for general indoor and outdoor coverage.

5.2.1.1 Uplink/downlink imbalance

It is broadly understood that the MFCN link budget is more challenging in the uplink than in the downlink. This is due to lower *e.i.r.p.* of MFCN UEs compared to MFCN BSs and applies irrespective of the frequency of the band. That is to say, imbalance between the link budgets of MFCN uplink and downlink is not specific to the Upper 6 GHz band, although it may be worse in the Upper 6 GHz band.

5.2.1.2 Comparison between 3.5 GHz and Upper 6 GHz bands

The 6 GHz indoor additional propagation losses (compared with 3.5 GHz) are assessed to come from free space path loss, clutter loss, building entry loss and sensitivity loss, with values as in Table 29.

Table 29: Radio propagation gap between the 3.5 GHz and upper 6 GHz bands (dB)

Additional loss	Downlink				Uplink			
	Trad.	Therm. Eff.	Trad.	Therm. Eff.	Trad.	Therm. Eff.	Trad.	Therm. Eff.
	Median		95th percentile		Median		95th percentile	
Free space	5.4				5.4			
Clutter	0.9				0.9			
Building entry	1.2	1.7	2.4	4.2	1.2	1.7	2.4	4.2
Sensitivity	2				1			
TOTAL	9.5	10	10.7	12.5	8.5	9	9.7	11.5
Note: Trad.: traditional; Therm. Eff.: thermally efficient Note: the 95 th percentile assumes that the coverage target would be 95% of indoor locations Note: the median values assume that the coverage target would be 50% of indoor locations								

The following improvement exploits the smaller wavelength of the upper 6 GHz band to obtain link budget improvements that are specific to the upper 6 GHz band:

- Improved Active Antenna Systems (AAS) support, resulting in 6 dB additional antenna gain when the number of antenna elements is doubled in both horizontal and vertical directions compared with a typical 3.5 GHz band product while keeping the antenna panel dimensions unchanged; this would lead to an equivalent improvement of 4 to 6 dB in the link budget at the MFCN 6 GHz BS in comparison to the 3.5 GHz band.

5.2.1.3 Evolution of buildings and technology

The evolution of buildings is expected to impact the MFCN link budget in all frequency bands. Should all buildings become thermally efficient, Recommendation ITU-R P.2109 [3] suggests that the propagation loss would increase by 11.7 dB at 3.5 GHz (see section 5.2.1.2 above for the difference between 3.5 and 6 GHz). It should be noted that solutions to mitigate additional building penetration losses due to thermally efficient materials already exist and may reduce this propagation loss in some cases [37], [38] and [39]. Coverage enhancements are being developed and standardised for MFCN BS and UEs in all bands. These enhancements would also be used to mitigate the additional losses described above, with the aim to deploy in the Upper 6 GHz band using the 3.5 GHz existing cellular grid in urban areas and additionally to provide similar outdoor and indoor coverage as delivered from the 3.5 GHz band.

- An increase in the number of antenna elements would provide an increase in antenna gain. Whereas there may be practical challenges that limit the size of the antenna panel, it is noted that even if the size is doubled (in comparison with a typical panel for 3.5 GHz) it remains smaller than what is used today for lower FDD frequency bands⁴. Without consideration of losses, e.g. related to multipath, such a panel would provide an additional 3 dB improvement in link budget, although further analysis would be required to provide a precise number on what is practically achievable.

⁴ In line with currently available 3.5 GHz commercial products, base stations' suppliers are considering future Upper 6 GHz products that will combine active Upper 6 GHz antennas and multi-band passive antennas (lower FDD bands) within one module without increasing the site footprint significantly (noting that current commercial products of this kind have sizes in the range of 2 m x 0.5 m). Base stations suppliers are also considering multi-band TDD active antennas which would combine the Upper 6 GHz AAS with the AAS of another TDD band (e.g. 3.5 GHz band) in one module while reusing the existing TDD band antenna surface at the site.

- In addition, the evolution of Massive MIMO platforms technology is enabling the progressive reduction in volume, weight, and power consumption of AAS products⁵.

The following improvements equally apply to the 3.5 GHz and to the Upper 6 GHz bands, but are relevant in the context of comparison between 3.5 GHz network deployments which are based on existing equipment capabilities and future deployments of Upper 6 GHz:

- When possible (depending on the UE form factor⁶), doubling the number of antennas at the UE, would result in up to 3 dB gain in both downlink and uplink.
- At lower order modulations (i.e. at edge of coverage), and when other radios are not in use in the device, it may be possible (depending on the UE form factor⁶), to leverage UE higher power classes⁷ resulting in 6 dB improvement in uplink.
- Leveraging recent 3GPP uplink coverage enhancement features such as uplink waveform switching, would result in 1.5-2.5 dB improvement of the link budget at low throughput.

Table 30: Coverage enhancements to help addressing the coverage gap between the 3.5 GHz and Upper 6 GHz bands (dB)

	DL		UL	
	min	max	min	max
Link budget improvement due to the enhanced BS AAS technology (Note 1)	4	9	4	9
UE Analogue Beam Forming (2x antennas) (Note 2)	3	3	3	3
UE power increase (Note 2)	N/A	N/A	3	6
UL waveform switching	N/A	N/A	1.5	2.5
Total for UE with all enhancements	7	12	7	20.5
Total for UE without power increase and without additional antennas	7	12	5.5	11.5
Note 1: The actual value within the range would depend on the products implementations				
Note 2: For example, it would be easier to double the number of transmit antennas and UE TX power for laptops and CPEs than it would be for smart glasses or smart watches.				

The coverage enhancements described above help to address the radio propagation gap between existing 3.5 GHz and the Upper 6 GHz band. While some enhancements might be more applicable or more widely implemented at Upper 6 GHz compared to 3.5 GHz, some may be applicable to both bands.

Based on ongoing research trends within mobile industry, it is also expected that 6G will target coverage enhancement in both FDD and TDD bands as a native design objective. Some of the features which are expected to result in coverage improvement in TDD bands include improvements in Downlink (e.g. broadcast channel optimisation), Uplink (included but not limited to waveform, MIMO, Control and Data Channels design, Sounding), and Power (flexible power allocation for Component Carriers, advanced duplexing, integrated, multi-carrier design). It is expected that 6G coverage enhancement techniques, together with the other RF enhancement already described, will allow to bridge the radio propagation gap between existing 3.5 GHz and future Upper 6 GHz.

⁵ For example, with new technologies for filters, power amplifiers, and radomes. Increasing the number of transceivers will not necessarily increase power consumption due to the adoption of techniques that dynamically account for end users' behaviour by switching on/off the number of transceivers based on traffic load.

⁶ For example, it would be easier to double the number of transmit antennas and UE TX power for laptops and CPEs than it would be for smart glasses or smart watches.

⁷ The 5G NR Release 19 change request introducing the support for UE power class 1.5 in the Upper 6 GHz band was endorsed at 3GPP TSG-RAN4 Meeting #112 (https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_112/Docs/R4-2411739.zip).

5.2.1.4 Considerations on MFCN network layers

Should MFCN in the Upper 6 GHz band be deployed as an additional capacity layer, MFCN carrier aggregation could mitigate degradation of the link budget by combining or switching carriers in the Upper 6 GHz band with carriers from lower frequency bands, enabling uplink coverage and capacity to be optimised. The discussion in section 2.4 on the assumptions for the use of the band should be noted in this context. This is similar to what has been done for the 3.5 GHz deployments where the deeper indoor performance is improved by aggregating the 3.5 GHz carrier with other carriers from lower frequencies.

5.2.2 6 GHz trials using 3.7 GHz macro sites

5.2.2.1 Summary

Two trials were conducted to demonstrate the feasibility of a macro deployment of 6 GHz MFCN based on macro sites operating in the 3.7 GHz band.

- 1 The first trial indicates that the Upper 6 GHz band is feasible to provide similar coverage to the 3.7 GHz band. The cell radius of a 6 GHz macro-cell can be larger than 500 m, comparable to the 3.7 GHz band and provide similar indoor penetration.

Outdoor throughputs up to 1.2 Gbit/s were achieved using 80 MHz bandwidth in good radio conditions and line-of-sight using 6 GHz band.

Indoor throughputs of up to 535 Mbit/s were achieved at different indoor test locations.

Building entry loss measured was approximately 25 dB for the double layer glass wall.

- 2 The second trial focussed on the aggregation of the 3.7 GHz band and Upper 6 GHz.

This 6 GHz and 3.7 GHz band trial in real field environment resulted in a data throughput of more than 12 Gbit/s using 100 MHz of the 3.7 GHz band and 400 MHz of the Upper 6 GHz band.

This throughput has been achieved in good radio conditions and line-of-sight.

5.2.2.2 Trial description

Radio propagation and MFCN throughputs at the Deutsche Telekom premise in Bonn (Germany) were measured in the first trial. The second trial has been conducted in a sub-urban scenario in Alzey (Germany). Both trials have used an active 6 GHz antenna unit operating in a macro base station with an operating bandwidth of 80 MHz, respectively 400 MHz. In Alzey, an additional 3.7 GHz antenna using 100 MHz has been used. The target of both demonstrations was to assess propagation characteristics and achievable data throughputs depending on distance from transmitter location.

The results confirm the expected performance of MFCN macro networks providing mobile services in the Upper 6 GHz band. These results can support the assessment of different sharing scenarios and to verify theoretical study results.

5.2.2.3 Technical parameters

For both trials the MFCN base station was located in a sub-urban environment with commercial/industrial buildings. Antenna height was above surrounding clutter. The Bonn trial used an output power of 39 dBm and 33 dBi antenna gain, resulting in an *e.i.r.p.* of 72 dBm. The system was operated in the frequency range 7035-7115 MHz. In Alzey, the 3.7 GHz was operated with an *e.i.r.p.* of 66 dBm, 39 dBm output power plus 27 dBi antenna gain. The 6 GHz system used an *e.i.r.p.* of 63 dBm, 41 dBm output power plus 22 dBi antenna gain.

5.2.2.4 Methodology

Downlink and uplink throughput were measured in various measurement points and distances to the base station under different angles vs boresight. Measurements were performed under LOS and NLOS conditions both indoors and outdoors.

5.2.3 Espoo 6 GHz trial

5.2.3.1 Summary

A field trial was performed in Espoo, Finland. The intention of the trial was to measure the outdoor performance of the Upper 6 GHz band in a macro-cell site and compare it to the performance of the 3.5 GHz band deployed in the same site.

- **Downlink performance:** Downlink received signal levels were measured at distances of 100-1000 m from the base station. Based on the measured RSRP values it was concluded that downlink performance of the Upper 6 GHz band equals the performance of the 3.5 GHz band up to 650 m from the rooftop base station antenna in an outdoor environment if a standard macro set-up (including transmission power) is used in both bands. In addition, it was concluded that the Upper 6 GHz downlink performance is at good level also beyond 650 m.
- **Uplink performance:** At the distance of 250 m from the base station, UL data rates of 104 Mbps were reached in the Upper 6 GHz band, and UL data rates of 118 Mbps were reached in the 3.5 GHz band with the 60 MHz bandwidth and TDD frame DDDSU used in both bands. Due to the limitations in this test set-up (e.g. UL beamforming capabilities in the used prototype BS equipment) the results beyond 250 m were not comparable between the Upper 6 GHz and 3.5 GHz bands.

While recognising the limitations of the current test set-up (i.e. parameters allowed in the test license, and prototype equipment in the Upper 6 GHz band vs. commercial equipment in the 3.5 GHz band), the trial demonstrated the capability of the Upper 6 GHz band with Massive MIMO antennas to provide significant additional capacity in the mobile network with the existing cellular grid. Further measurements are being planned for more comprehensive results, including also indoor coverage performance.

5.2.3.2 Trial description

Upper 6 GHz and 3.5 GHz base station antennas were placed in an existing rooftop site in Espoo. Main beams were pointing along a railway track.

Downlink received signal levels were measured at distances of 100 m, 250 m, 490 m, 650 m, 790 m, and 1000 m from the base station. Propagation path was LOS, except for the measurement point at 1000 m. Uplink data rates were measured at the distance of 250 m from the BS.

5.2.3.3 Technical parameters

The following technical parameters were used:

- **Base station:** Base station antennas were placed at a rooftop at 23 m height above ground. In the Upper 6 GHz band, a prototype equipment using a 128 TRX Massive MIMO antenna was used. In the 3.5 GHz band, commercially available equipment with 64 TRX Massive MIMO antenna was used.
- The test licenses set some limitations to the measurements. This is why transmission power of 52 dBm was used in the Upper 6 GHz band. 75 dBm transmission power was used in the 3.5 GHz band. This difference was considered when deriving conclusions from the RSRP measurements.
- 60 MHz bandwidth and TDD Frame structure DDDSU were used in both bands.
- **Terminal:** A test terminal with integrated antennas, 2TX/4TX channel, and transmission power of 24 dB was used. The terminal supported both 3.5 GHz and Upper 6 GHz bands.

5.2.3.4 Methodology

RSRP was measured at distances of 100-1000 m from the base station. UL data rates were measured at 250 m. Measurements were performed outdoors mainly under line-of-sight conditions.

5.2.4 Stuttgart 6 GHz trial

5.2.4.1 Summary

The trial aimed at measuring the performance of Upper 6 GHz MFCN using existing macro MFCN base station locations, and showed a coverage equivalent to 3.5 GHz.

Indoor coverage was achieved at 170 and 240 m distance producing downlink throughputs between 500 and 1300 Mbps in NLOS conditions while still maintaining the 6 GHz band uplink. In a real network implementation where 6 GHz is aggregated with lower frequency bands, downlink service may be available at lower than -119 dBm RSRP levels, assuming that uplink uses other bands with better signal propagation.

Outdoor downlink throughputs up to 2.8 Gbit/s were achieved using 100 MHz bandwidth in good radio conditions and line-of-sight.

Outdoor coverage up to 500 m range was measured in the trial, still maintaining downlink performance above 400 Mbps and sufficient uplink signalling in the 6 GHz band .

Building entry loss measured was 21 dB for double-glazed, thermally active windows.

Downlink performance remains above 400 Mbps if RSRP levels remain at or above -115- -120 dBm.

5.2.4.2 Trial description

Radio propagation and MFCN throughputs in an urban scenario was tested in a field trial in Stuttgart, Germany, with an Upper 6 GHz active antenna unit operating in a macro base station with an operating bandwidth of 100 MHz. The target of the test was to assess propagation characteristics and signal strength depending on distance from transmitter location and assess achievable throughputs in uplink and downlink.

The results help to assess the performance of MFCN macro networks and the signal levels allowing the provision of mobile services in the Upper 6 GHz band. This can help assessing different sharing scenarios to make informed decision regarding required sensing approaches and appropriate EDTs. Trial results also could help to verify theoretical studies results.

5.2.4.3 Technical parameters

The MFCN base station was located in an urban environment with commercial/industrial buildings. Antenna height was 75 m above ground level, above surrounding clutter. The setup was tested using an output power of 100 W and 22 dBi antenna gain, resulting in *e.i.r.p.* of 72 dBm. The system was operated in the frequency range 6475-6575 MHz stand-alone (i.e. without reliance on other frequency band as anchor/signalling layer) and in TDD mode using a DDDSU frame structure (76.5% of resources configured for downlink).

5.2.4.4 Methodology

Downlink and uplink throughput as well as reference signal level/RSRP was measured systematically in various distances to the base station under different angles vs boresight. Measurements were performed under line-of-sight and non-line-of-site conditions both indoors and outdoors.

5.2.5 Reference indoor performance levels for standard power MFCN base stations operating in the upper 6 GHz band

5.2.5.1 Summary

- Field trials detail the reference indoor performance levels that can be expected from MFCN base stations operating in the 6 GHz band in urban-type macro-cell environments, where it is expected 6 GHz MFCN base stations would be primarily deployed for coverage and capacity.
- The trial highlights the impact of restricting base station power levels. The trial shows a 3 dB reduction in base station power levels results in a mean downlink throughput reduction of around 61% across 20% of the poorest indoor coverage locations and in some cases the power reduction results in no coverage.
- The impact of bandwidth on performance is also assessed through conducting measurements with 200 MHz channel bandwidths. The results show throughput levels with 200 MHz channels provide a step increase in performance over 3x GHz network deployments today typically operating with channel bandwidths of around 100 MHz.

5.2.5.2 Trial description

The trial was conducted with prototype full power 6 GHz MFCN base station and UE equipment. The 6 GHz active antenna equipment was installed on an existing macro-cell rooftop site providing 5G coverage in the area using the 3 GHz band.

Indoor throughput performance was measured across 2 different areas:

- 1 Preliminary indoor coverage tests in large campus in Madrid which consists of around 5 connected multi-story buildings. The buildings' facade is predominantly thick re-enforced, thermally efficient glass and some metal panelling. Precise testing of the penetration loss for the glass was not possible however some measurements conducted estimated the loss to be in the range 24-30 dB.
- 2 A downtown area consisting of blocks of multi-storey buildings, typical of an urban environment. Indoor measurements were conducted in 3 ground floor restaurants within this urban-type environment. There were no direct signal paths from the antenna to any of these restaurants with at least 1 or 2 large buildings 'blocking' the direct line-of-sight path. Measurements were conducted in shallow indoor points near windows and deep indoor points within these restaurants.

5.2.5.3 Technical parameters

The prototype active antenna unit had a *e.i.r.p.* of 79 dBm, which was the power available at the time of the trial.

The system was operated in the frequency range 6425-6825 MHz with 100 MHz and 200 MHz bandwidth configurations and 4:1 (i.e. DDDSU) TDD DL/UL ratio. A test smartphone was used for the trial.

5.2.5.4 Methodology

Tests were carried out to assess indoor throughput performance levels in urban type environments, the impact of bandwidth on performance through conducting measurements with 100 MHz and 200 MHz channel bandwidths, and, to compare 3.5 GHz and 6 GHz coverage across these indoor areas under like-for-like conditions (same bandwidth and power).

5.2.6 Dallas MFCN/RLAN trial

5.2.6.1 Summary

Field trials were done at the Nokia campus in Dallas to assess the potential interference from co-channel WAS/RLAN to MFCN equipment that could occur in residences and enterprises, where the EDT was not

exceeded during the trial and the access point was locked to a frequency. The tests used prototype MFCN equipment and a Wi-Fi 6E LPI access point, operating within the 7000 to 7100 MHz frequency range.

The tests show that even in idle state, an LPI AP can cause a 10% to 20% throughput reduction to MFCN DL, at distances of 13 m and 4 m with respect to an achieved MFCN DL throughput of 130 Mbps and 100 Mbps respectively when the WiFi-AP was off. This is despite the low duty cycle of the idle state transmissions. In addition to the throughput reduction, DL channel state measurements are heavily impacted. UL throughput was not impacted significantly.

5.2.6.2 Trial description

An outdoor MFCN base station was operating under a trial license restricted to 7000-7100 MHz frequency range and limited output power (*e.i.r.p.* of 55 dBm). An MFCN UE with a maximum output power of 23 dBm was placed indoor at 150 m distance from the base station and set up with uplink and downlink transmissions. A Wi-Fi LPI AP was located in the same corridor as the MFCN UE and was either in an idle state in the default configuration (transmitting in this instance periodic beacons and discovery related signals), or turned off. The MFCN DL and UL performance was recorded with the Wi-Fi AP in idle state and turned off.

5.2.6.3 Technical parameters

Due to the trial spectrum license and prototype MFCN equipment restrictions, and the Wi-Fi 6E channel plan, partial frequency overlap was used in the test. The MFCN centre frequency was 7.05 GHz and channel bandwidth 60 MHz. The Wi-Fi AP was locked to centre frequency 7.025 GHz and 80 MHz bandwidth (channel 215). The resulting bandwidth overlap was 45 MHz out of the 60 MHz MFCN channel bandwidth.

MFCN was set up with full buffer DL and UL traffic. DL signal level indoors was -81 dBm to -74 dBm, sufficient for approximately 10-17 dB SNR. Throughput and DL channel state measurements were reported.

The Wi-Fi AP located either 13 m or 4 m distance from the MFCN UE. In idle state, it transmitted beacon frames at 102.4 ms intervals (duplicated to all four channels), and Fast Initial Link Setup (FILS) discovery signals at 20 ms intervals (also duplicated to all four channels). On average the duty cycle was determined to be 0.86%. Note that this configuration may be different in Europe.

5.2.6.4 Methodology

When the Wi-Fi AP was in the idle state, the impact from the beacon and discovery signal transmissions was recorded in DL and UL throughput, and the DL channel state measurements. These metrics were compared to the case when the Wi-Fi AP was turned off.

6 CONCLUSIONS

This Report examines potential approaches for shared use of the Upper 6 GHz band by MFCN and WAS/RLAN. Different sharing approaches and sharing mechanisms are discussed in section 3, some of which have been assessed in sharing studies within this Report. In all cases, practical implementation of these sharing mechanisms has not been considered, including identifying relevant requirements to be addressed in harmonised standards (by ETSI).

Various studies in this Report, summarised in section 4, consider the impact on performance from a network and user perspective of MFCN macro-cell coverage and capacity as well as spectrum access/throughput for WAS/RLAN due to shared use of the Upper 6 GHz band. Studies assess impacts of interference from the respective other application as well as the impacts of different MFCN BS *e.i.r.p.* levels. Some studies, assess the impact on both applications while others consider the impact for only one of the applications.

Most studies assume that WAS/RLAN would either cease transmission or take some other mitigating measure (such as switching to another channel) when an MFCN signal is detected above a given threshold (based on assuming successful reception and decoding of the relevant MFCN signals).

This Report includes studies assuming the standard WAS/RLAN Energy Detection mechanism (based on current standards in the Lower 6 GHz band), and studies with enhanced detection mechanisms i.e. cross-technology signalling.

Other sharing mechanisms and approaches, targeting identification/detection of WAS/RLAN systems by MFCN or using databases have also been initially considered and discussed in this Report (see section 3.4).

This section includes:

- results of studies for the feasibility of shared use by full power MFCN⁸ and WAS/RLAN (Low Power Indoor (LPI) and Very Low Power (VLP)) deployments with Energy Detection Threshold (EDT) only (see section 6.1);
- results for new sharing mechanisms through enhanced detection techniques to reduce the interference between applications by reducing the availability of spectrum for WAS/RLAN (see section 6.2);
- results of studies for MFCN outdoor coverage, WAS/RLAN indoor coverage through reduced MFCN BS *e.i.r.p.* (see section 6.3);
- MFCN Downlink/Uplink consideration and results of MFCN field trials (see section 6.4);
- issues for further consideration including band split approaches and interworking between MFCN and WAS/RLAN (see section 6.5).

A variety of sharing approaches and results on feasibility and sharing studies on the potential shared use of the 6425-7125 MHz frequency band between MFCN and WAS/RLAN are described in this section.

6.1 SHARING RESULTS FOR MFCN WITH FULL POWER AND WAS/RLAN (LPI AND VLP) WITH EDT ONLY

A number of studies in this Report examine the potential shared use between MFCN full power outdoor BS *e.i.r.p.* in the range of 73 to 83 dBm/100 MHz (and up to 87 dBm/100 MHz for a sensitivity analysis) and WAS/RLANs (LPI and VLP) with EDT only. MFCN BS *e.i.r.p.* levels that are consistent with expected equipment availability could enable the reuse of the existing 3.5 GHz MFCN BS sites (inter-site distance) without indoor and outdoor capacity loss. In this context, several studies evaluate the resulting availability of indoor locations where WAS/RLAN could operate, i.e., where received MFCN signal levels would be below the WAS/RLAN EDT of -84 dBm/MHz. These studies use a range of assumptions for the MFCN and WAS/RLAN deployments and parameters.

⁸ Values of MFCN base station *e.i.r.p.* cited in this Report refer to the *e.i.r.p.* in the main beam direction. In the context of this Report, “full power” MFCN base stations means MFCN base stations radiating at high *e.i.r.p.*

All LPI based studies in this category assume that WAS/RLANs would use a “detect-and-avoid/listen-before-talk” mechanism that triggers when the MFCN signal level is above the EDT. This means that WAS/RLAN equipment that are within the range of a MFCN BS would not transmit due to received MFCN signal levels being above the EDT, whereas WAS/RLAN equipment at locations with lower MFCN signal levels (e.g. due to higher path losses) would continue to transmit. This can lead to decreased SINR for both WAS/RLAN and MFCN receivers.

This Report indicates that shared use between MFCN with full power and WAS/RLANs operating on the same frequency/channel is not possible without negative consequences for WAS/RLAN spectrum access and user experience.

In some cases, interference to MFCN would also be caused from WAS/RLAN LPI and WAS/RLAN VLP equipment.

6.1.1 Probability of WAS/RLAN energy detection of MFCN

A number of studies specifically examine the probability of WAS/RLANs successfully detecting the presence of MFCN signals using the WAS/RLAN energy detection approach based on Wi-Fi technical standards [25] (i.e. the standard WAS/RLAN EDT).

Study C1/D4 (see section 4.1) indicate that assuming a standard WAS/RLAN EDT of -84dBm/MHz, and with the MFCN parameters of section 2 (BS *e.i.r.p.* of 73 dBm/100 MHz and 300 m cell range), WAS/RLANs would be able to detect the presence of urban macro-cellular MFCN at around 30% of the simulated indoor locations.

Study D1 (see section 4.2) indicates that with a higher MFCN BS *e.i.r.p.* of 81.6 dBm/80 MHz, WAS/RLAN equipment using standard EDT could detect the presence of MFCN at 100% of outdoor locations and 75% of indoor locations within a cell.

Study C7 (see section 4.17) indicates that with the MFCN BS *e.i.r.p.* ranging from 67 to 87 dBm/80 MHz, the received MFCN power exceeds the standard WAS/RLAN EDT in 50% to 90% of indoor locations.

Study C3 (see section 4.12) indicates that the presence of MFCN downlink traffic signals would be detected by WAS/RLANs in around 53% of indoor locations and almost all outdoor locations within an MFCN cell for a MFCN BS *e.i.r.p.* of 72 dBm/80 MHz.

On the other hand, study C4 (see section 4.15), which assumes a higher building entry loss, indicates that in the studied area of a European city, only about 8% of indoor MFCN downlink signal levels were above the WAS/RLAN standard EDT of -84 dBm/MHz for a MFCN BS *e.i.r.p.* of 80 dBm/100 MHz, and only around 1% for a MFCN BS *e.i.r.p.* of 74 dBm/100 MHz.

Study A1 (see section 4.5) indicates that WAS/RLANs using standard EDT can detect the presence of MFCN in 4.4% of indoor locations for a MFCN BS *e.i.r.p.* of 73 dBm/100 MHz.

6.1.2 Impact on WAS/RLAN spectrum access and performance

The studies in section 6.1.1 indicate that full power MFCN macro-cellular BSs negatively impact spectrum access for WAS/RLANs where shared use between full power outdoor macro-cell BSs and WAS/RLANs occur in the same geographical areas. Studies indicate that depending on the density and loading of the MFCN as well as the MFCN BS *e.i.r.p.*, up to 90% of indoor locations could become unavailable for WAS/RLAN use. This is based on the assumption that WAS/RLANs would use listen-before-talk or sense-and-avoid techniques such that WAS/RLANs would not transmit in the channel or would vacate the channel when the MFCN signals exceed the EDT. The exact percentage of detection (and therefore unavailability) varied across studies, influenced by differing parameters and assumptions, including whether the MFCN BS *e.i.r.p.* would be higher than the 73 dBm/100 MHz.

The following studies indicate that where the MFCN signal is below the WAS/RLAN EDT, WAS/RLAN throughput may be reduced as a result of the SINR degradation caused by the MFCN signal.

Study C6 (see section 4.17) indicates that assuming a MFCN BS *e.i.r.p.* of 73 dBm/(100 MHz), indoor WAS/RLAN APs are expected to be affected by interference above the noise floor from MFCN BSs with a probability of between 60% and 90% of the cases observed.

Study C7 (see section 4.18) indicates that the average WAS/RLAN capacity would be degraded to between 50% and 10% due to interference from MFCN BS with a BS *e.i.r.p.* between 67 dBm/80 MHz and 87 dBm/80 MHz compared to the case without interference. Study C3 (see section 4.12) indicates that the WAS/RLAN communication range would be reduced to less than 5% of its non-interfered value in an additional 7% of indoor locations where MFCN signal levels are below EDT, taking the total indoor locations where WAS/RLAN would be unavailable or significantly degraded to around 60% of indoor locations within the MFCN cell as a result of MFCN BS transmissions with an *e.i.r.p.* of 72 dBm/100 MHz.

Study A1 (see section 4.5) indicates that for MFCN BS of 73 dBm/100 MHz *e.i.r.p.*, an additional 5.9% of WAS/RLANs are degraded below their minimum SNR requirements, result in a combined 10.3% of WAS/RLANs being unable to operate (when combined with those locations that are above the EDT where WAS/RLANs do not transmit).

6.1.3 Impact on MFCN macro-cell coverage and capacity from a network and user perspective

Study C2 (see section 4.11) studies the impact on MFCN downlink performance due to WAS/RLAN transmissions. Based on its analysis (also in study C3 - see section 4.12) that 47% of indoor locations could still be available for WAS/RLAN use, it indicated MFCN downlink throughput based on a BS *e.i.r.p.* of 72 dBm/80 MHz would be reduced to zero in around 49% of indoor locations within the coverage area of the MFCN where a WAS/RLAN transmits within 10 m of an MFCN UE which is receiving at the same time (up from 12% of locations when no WAS/RLAN interference was present). Even when the MFCN UE is outdoors (assuming a 15 dB loss through a brick wall), MFCN downlink throughput would be reduced to zero in 40% of outdoor locations when the receiving UE is within 10 m of an indoor WAS/RLAN which transmits at the same time. The likelihood of these close proximity scenarios would depend on the number of WAS/RLAN equipment and UEs within the MFCN cell area.

Study C9 (see section 4.13) studies the interference from both LPI and VLP devices. For the full WAS/RLAN LPI and VLP deployment the results indicate that performance of an MFCN system median downlink throughput would be degraded by 26%, and the cell edge (5th percentile) by 53% (under the assumption that active WAS/RLAN always operate within 40 m from UEs) if co-channel WAS/RLAN operates in the same area without additional sharing mechanisms.

For VLP devices only, an effective RF activity factor of 20% was used to model the impact on MFCN downlink (based on the highest of the two mean throughput degradation levels in a trial). Assuming that the VLP client fails to select a clear channel, simulation results indicate an impact on MFCN downlink throughput and SINR in scenarios with clustered assumption of VLP and MFCN devices. In the absence of a sharing mechanism, MFCN downlink throughput can be reduced by 9.1% for the median user and by 40% for the cell edge user by VLP activity. Further study would be required to understand the impact for indoor-only and outdoor-only scenarios. The deployment assumption makes a difference to the severity of interference, a clustered device deployment assumption being worse for coexistence.

Study C10 (see section 4.19) studies the use of indoor and outdoor VLP devices, assuming a MFCN BS *e.i.r.p.* of 70 dBm/100 MHz. For a 1.97% VLP activity factor, implying 3 VLP devices transmitting simultaneously in a 5 km² area, there was no discernible degradation in MFCN uplink performance for each UE within the simulation area. With a much higher activity factor of 20% as a sensitivity analysis, implying 30 VLP devices transmitting simultaneously in a 5 km² area, there was a 2 Mbps degradation in UE uplink performance as a result of interference from VLP devices. The impact of MFCN on VLP was not studied and it was suggested that energy detect would prevent the VLP device from transmitting and would mitigate some of the uplink performance degradation in the studies. There was no degradation in MFCN downlink performance in any of the scenarios considered, subject to the modelling assumption that the locations of active MFCN UEs and VLP devices are uncorrelated, such that the likelihood of them being located in close proximity is close to zero.

The level of VLP and UE location correlation affects the severity of interference. Further investigation may be needed to assess the likelihood of the co-located scenarios.

6.2 ENHANCED DETECTION TECHNIQUES

The previous section describes the impact on spectrum access for WAS/RLAN due to MFCN signals above the EDT as well as degradation of WAS/RLAN and indoor MFCN UE performance when WAS/RLAN continues to transmit (due to received MFCN signal levels being below the EDT). The level of impact on one application from the other varies based on the signal level (sensitivity) of detection.

Enhancing the WAS/RLAN detection of MFCN could improve detection of MFCN signals and enable further scenarios for shared use of the Upper 6 GHz band. Detection of WAS/RLAN by MFCN and using databases have been described as potential additional new mechanisms which could enable further scenarios for shared use of the Upper 6 GHz band.

6.2.1 Enhanced detection of MFCN signals by WAS/RLAN

In addition to the energy detection mechanism, three new detection techniques to improve the detection of MFCN signal by WAS/RLAN equipment have been explored:

- WAS/RLAN equipment decodes an IEEE 802.11bc signal which is broadcasted by MFCN BSs (and in some cases by UEs as well);
- WAS/RLAN equipment decodes the 5G NR synchronisation signal block (SSB) signal which is broadcasted by MFCN BSs.

In addition, WAS/RLAN detecting on-off keying on MFCN signals has been discussed in section 3.4. Further work is needed to develop this mechanism in particular to determine the detection threshold and mitigating actions. Consequently, studies would be needed to investigate the effectiveness of detection.

These techniques would not impact existing WAS/RLAN sharing mechanisms based on using EDT for identifying other uses.

The detection probabilities of these new techniques is compared to the detection probability using standard energy detection at received power level of -84 dBm/MHz. This assumes that the relevant signals have sufficient SINR or received power to be successfully decoded.

6.2.1.1 IEEE 802.11bc based detection

In this option, the MFCN broadcasts an IEEE 802.11bc UL signal with Higher Layer Payload (HLP). WAS/RLANs would need to take action in response to this signal in order to avoid transmitting in the entire channel used by the MFCN.

Study D9 (see section 4.3) looks at cross-technology signalling using different detection thresholds. Using IEEE 802.11bc cross-technology signalling with a 4 dB SINR threshold for detection, 67% and 12% of indoor WAS/RLAN AP locations are reported as detecting the signal with power above -95 dBm/MHz when transmitted by MFCN Base Stations (Broadcast beams) with an BS *e.i.r.p.* of 73 dBm/100 MHz and MFCN User Equipment respectively. The results also show higher detection (99%) when MFCN UEs are located within a 10m range of the AP).

Study A1 (see section 4.5) indicates that if WAS/RLANs defer to an MFCN signal at or above a -95 dBm/MHz threshold, then 12.5% of WAS/RLANs are unable to access the channel.

Study A3 (see section 4.7) indicates that only 25-35% of indoor locations would be available for WAS/RLAN with an MFCN *e.i.r.p.* of 73 dBm/100 MHz based on the assumption that WAS/RLAN would “detect and avoid” the channel if MFCN signals are above the signal detection threshold for IEEE 802.11bc.

Study D10 (see section 4.4) indicates that with a MFCN BS *e.i.r.p.* of 82 dBm/80 MHz, indoor WAS/RLAN equipment would be able to successfully decode the IEEE 802.11bc signals transmitted by MFCN BSs in around 45% of indoor locations within an MFCN cell. With the MFCN BS *e.i.r.p.* reduced to 57 dBm/80 MHz, the corresponding proportion of locations reduces to around 30%.

6.2.1.3 SSB based detection

The SSB signal is standardised for 5G NR and enables UEs to detect the presence of MFCN as part of the networks' normal operation. In this option, WAS/RLANs would need to decode the 5G SSB signals broadcasted by the MFCN and to take action to avoid transmitting in the entire channel used by the MFCN.

Study C1 (see section 4.1) and D4 (see section 4.1) extends its analysis to consider the detection of the SSB signals from the MFCN broadcast beam based on a BS *e.i.r.p.* of 83 dBm/100 MHz with an SINR threshold of between -5 and -8 dB depending on the receiver architecture. For a similar urban macro-cell environment WAS/RLAN is shown to fail to detect the MFCN SSB signal in only around 4% of the simulated locations.

Study D1 (section 4.2), assuming an MFCN BS *e.i.r.p.* of 82 dBm/100 MHz, finds that the WAS/RLAN equipment is able to successfully decode the transmitted SSB pilot signals in virtually all outdoor locations, and in 98% to 99% of indoor locations within an MFCN cell.

Study D10 (see section 4.4) further indicates that with the MFCN BS *e.i.r.p.* reduced to 57 dBm/80 MHz, the corresponding proportion of indoor locations where WAS/RLAN equipment can successfully decode the SSB pilot signals reduces to around 65% to 75%.

6.2.2 Benefits of enhanced detection techniques for MFCN and WAS/RLANs

The new detection techniques described above might improve the detection of MFCN signal by WAS/RLANs compared to WAS/RLAN standard energy detection and would not impact existing WAS/RLAN sharing techniques (based on Energy Detect as currently specified by IEEE). The technique based on SSB decoding remains effective at a lower SINR levels compared to the decoding of IEEE 802.11bc.

Considering power-based thresholds (relevant in noise-limited locations), the new detection techniques described in section 6.2.1 could be used to improve the probability of detecting MFCN for both the case with full power MFCN BS in section 6.1 and for the case with reduced power MFCN BSs in section 6.3. Initial studies in this Report, indicate that the probability of detection is greater with higher MFCN BS *e.i.r.p.* However, studies also indicate that when considering SINR-based thresholds (relevant in interference-limited locations) the above trends may no longer apply.

6.2.3 Drawbacks of enhanced detection techniques for MFCN and WAS/RLAN

All enhanced detection options above require MFCN to broadcast signals and for the relevant MFCN BS and WAS/RLAN features to remain unchanged in the future, even when MFCN or WAS/RLAN technologies evolve. They also imply additional standardisation in order to embed either a 3GPP component (SSB) in IEEE standards, or an IEEE component (802.11bc) in 3GPP standards, or an on-off keying component in both IEEE and 3GPP standards.

Studies in this Report assume perfect detection of MFCN signals above the relevant threshold and do not take into account practical considerations which may affect their effectiveness. Such considerations include signal propagation challenges like hidden terminals and dynamic environments which may need to be further studied (see section 6.5).

Using MFCN to broadcast IEEE 802.11bc signals would limit the majority of changes to the MFCN BS side (hardware and software) and to WAS/RLAN equipment that is not based on Wi-Fi. Decoding of SSB by WAS/RLANs would mean that the majority of changes would be required on the WAS/RLAN APs (non-AP could also implement this). Using an on-off keying component requires an update to MFCN and WAS/RLAN equipment.

Finally, it should be noted that all cross-technology signalling options require transmission of specific signals (either based on existing technologies, or new signals to be defined). All these schemes would need to be standardised, harmonised and tested for compliance.

This is discussed in more detail in section 3.4. It is noted that there is no common view from industry in favour of one of the option or another option. All options based on power-based thresholds (relevant in noise-limited locations) reduce the amount of indoor spectrum access for WAS/RLAN compared to using standard energy

detect, although this may not necessarily be the case for SINR-based thresholds (relevant in interference-limited locations), depending on the BS *e.i.r.p.* level. However, they also reduce the occurrences of performance degradation on both the WAS/RLAN and the MFCN side. This trade off may be informed by future work on spectrum needs of both applications.

A channel frequency arrangement has also been proposed in section 3, whereby MFCN would use an 80 MHz channel plan aligned with that of WAS/RLAN. This approach would be helpful to ensure that MFCN IEEE 802.11bc or SSB signalling is aligned with the WAS/RLAN primary scan channel which is expected to simplify detection. However, no studies have been conducted to confirm this issue. This requirement could impact the flexibility of MFCN in the future to have smaller or larger block sizes, which could impact the development of MFCN in the band.

6.2.4 Detection of WAS/RLAN by MFCN

Study A1 (see section 4.5) indicates that for MFCN BSs transmitting at an *e.i.r.p.* of 55 dBm/100 MHz and if MFCN UEs were to defer at a received WAS/RLAN power level of -95 dBm/MHz or greater (i.e. where MFCN UE detects a WAS/RLAN frame), then 0.16% and 0.18% of MFCN UEs would vacate the channel considering a single MFCN BS and a cluster of seven MFCN BS respectively.

No other sharing studies were undertaken. However, section 3 of this Report discusses various other sensing and signalling techniques that may be of use in allowing MFCN to detect WAS/RLAN signals:

- MFCN detection of WAS/RLAN would need to rely on smartphone assistance due to the power difference between the MFCN BSs and the WAS/RLAN APs. With this mechanism, MFCN UEs could act as geographically distributed sensors for detecting the presence of WAS/RLANs in channels in the Upper 6 GHz band and could subsequently inform MFCN BSs to take appropriate actions to avoid harmful interference to the WAS/RLANs, e.g. by vacating the channel. No assessment of the reliability of this approach has been undertaken;
- Where indoor UEs are being served by MFCN, Study C2 (see section 4.11) indicated that they have the potential to cause interference to, or suffer interference from, indoor WAS/RLANs where they are deployed. The same smartphone sensing technique described above could also be used to assist in avoiding interference in this situation. However, the actions could be different in order to avoid a single WAS/RLAN device causing an entire MFCN BS to be switched off.

6.2.5 Using databases

Databases could also assist with geographical, frequency or even time separation. These databases could allow flexibility in the priority between services assigned by a national administration at a particular location and/or time, although cross-border arrangements would need to be respected.

However, detailed implementation of such approaches has not been studied in this Report. Different initiatives within ECC in recent years on database solutions for WAS/RLAN have not led to harmonised practical implementations in CEPT.

6.3 MFCN OUTDOOR COVERAGE AND WAS/RLAN INDOOR COVERAGE THROUGH REDUCED MFCN BS *E.I.R.P.*

This sharing approach assumes that in the same geographical (urban) area, MFCN are intended to primarily provide outdoor coverage, and WAS/RLANs are intended to primarily provide indoor coverage, noting that the coverage will spill outside those outdoor/indoor areas. The main approach that has been studied is to reduce the *e.i.r.p.* of the MFCN base stations in order to reduce the MFCN signal levels indoors. One study has coupled this approach with enhanced detection techniques.

6.3.1 Spectrum access and sharing performance for WAS/RLAN

Some studies in this Report indicate that co-channel coexistence between indoor WAS/RLANs and outdoor MFCN could potentially be improved by MFCN BSs with a *e.i.r.p.* in the range of 50 to 57 dBm/100 MHz.

Study A3 (see section 4.7) indicates that at an MFCN BS *e.i.r.p.* level of 57 dBm/100 MHz in a network with 10 BS/km², around 80% of indoor WAS/RLAN locations would support the use of the Upper 6 GHz, with the remaining locations receiving IEEE 802.11bc uplink frames from 6 GHz BSs above the signal detection threshold, which is assumed to block their access.

Study A1 (see section 4.5) considers that sharing was possible with a MFCN *e.i.r.p.* level of 55 dBm/100 MHz in a 300 m cell radius with sufficient separation distances between MFCN and WAS/RLANs. It also indicates that 3.5% of indoor WAS/RLANs could not connect or would vacate the channel. Studies B2 (see section 4.9) and B3 (see section 4.10) consider that sharing was possible with an MFCN *e.i.r.p.* level of 53 dBm/ 80 MHz and 27-50 dBm/ 80 MHz at 300 m cell range respectively for their particular study areas.

Study B3 (see section 4.10) indicates that with an MFCN *e.i.r.p.* of 40 dBm/80 MHz in the modelled area of Copenhagen over 90% of the MFCN outdoor capacity was achieved over a cell range of 200 m with similar percentage of WAS/RLAN indoor capacity achieved when compared to the non-shared case. This study indicates that the combined capacity of indoor WAS/RLAN and outdoor MFCN under such conditions is higher than the capacity of either system in a non-sharing scenario.

Study B2 (see section 4.9) quantifies the SINR degradation of WAS/RLANs compared to when no sharing was present. It indicates that with a reduced MFCN BS *e.i.r.p.* of 53 dBm/80 MHz, WAS/RLANs still had a SINR degradation of 10 dB compared to exclusive use. There was also a corresponding degradation in UE SINR of 5 dB (compared to when using an *e.i.r.p.* of 68 dBm/80 MHz) as a result of the APs continuing to transmit in the presence of MFCN signals.

Studies B2 and A3 (see section 4.9 and 4.7) indicate that throughput degradation for both applications could be reduced through cross-technology signalling by MFCN whereby WAS/RLANs would detect MFCN at lower signal levels than would be possible with the standard energy detection approach. This would allow WAS/RLAN to avoid channels utilised by MFCN in the area, resulting in reduced degradation of the spectrum for both applications but also reduced spectrum access for WAS/RLAN.

Study B2 (see section 4.9) indicates less interference when taking account of improved IEEE signal detection at -94 dBm/MHz (-75 dBm/ 80 MHz) relevant in noise-limited locations.

Study A3 (see section 4.7) indicated that around 2%-4% of WAS/RLAN access points, 2%-3% of BS beams and 1% of modelled outdoor UE locations could still suffer performance degradation as a result of MFCN BS signal levels below these reduced detection thresholds not being detected by WAS/RLAN. If WAS/RLAN were only deployed indoors then Study B3 (see section 4.10) indicates that MFCN may be able to use outdoor small cells at a BS *e.i.r.p.* of around 40 dBm/ 100 MHz.

6.3.2 Outdoor MFCN coverage/capacity as a result of reduced MFCN *e.i.r.p.*

Study A3 (see section 4.7) indicates that for a MFCN BS *e.i.r.p.* of 57 dBm/100 MHz, MFCN access to the Upper 6 GHz band supporting for instant video playback would be possible from around 73% of outdoor locations (a lower level of service would be available at more outdoor locations). It also indicates that when the Upper 6 GHz is considered as an additional capacity layer of the same MFCN network, the achieved predominantly outdoor MFCN capacity still led to a doubling of the overall capacity compared to a 3.5 GHz network layer on its own. This improvement was observed when a similar bandwidth Upper 6 GHz channel was added and when indoor and outdoor users were optimised between the two bands and with network loading targeted to 50%, aligned with the assumptions in section 2. Based on the assumptions in this study, the Upper 6 GHz band supported more outdoor traffic than the 3.5 GHz band.

Study A3 (see section 4.7) indicates that 57 dBm/100 MHz MFCN *e.i.r.p.* levels cause the cell to shrink but still provide outdoor coverage exceeding the 300 m cell range assumption outlined in section 2. 41% of UEs that could access the 3.5 GHz band could also access the 6 GHz network, increasing to 60% for lower throughput coverage.

Study B3 (see section 4.10) indicates that with an MFCN *e.i.r.p.* of 40 dBm/80 MHz in the modelled area of Copenhagen over 90% of the MFCN outdoor capacity was achieved over a cell range of 200 m. This suggests that capacity could be achieved even in conditions where coverage may be challenging.

Study E1 (see section 5.1) studied the impact of reduced MFCN BS *e.i.r.p.* compared to a network based on 81 dBm/100 MHz. It indicates that a reduction from 81 dBm/100 MHz to 70 dBm/100 MHz results in an 11% reduction in average outdoor downlink throughput, and a 66% reduction in the cell-edge (5th percentile) outdoor downlink throughput (spectral efficiency reduction from 0.35 to 0.12 bit/s/Hz). A reduction of MFCN BS *e.i.r.p.* from 81 dBm/100 MHz to 60 dBm/100 MHz results in a 22% reduction in average outdoor downlink throughput, and a 99% reduction in the cell-edge outdoor downlink throughput (spectral efficiency reduction from 0.35 to 0.004 bit/s/Hz).

Study A1 (see section 4.5) indicates that for a MFCN BS *e.i.r.p.* of 55 dBm/100 MHz in a 300 m cell the percentage of outdoor UEs that are unable to connect due to being below MFCN BS downlink minimum SNR requirement was 6.7% and that 8.4% of UEs would not be able to connect in the uplink.

6.3.3 Overall MFCN coverage / capacity as a result of reduced MFCN BS *e.i.r.p.*

Several studies and trials indicate that reduced MFCN BS *e.i.r.p.* levels would negatively impact the MFCN coverage and capacity when using the existing 3.5 GHz cellular grids, leading to limited coverage. Some studies indicated little to no impact on outdoor coverage/capacity, while others indicated significant reduction in outdoor capacity/coverage in the Upper 6 GHz band.

Indoor coverage/capacity information is provided here for completeness. However, it is noted that where MFCN BS *e.i.r.p.* is reduced in order to facilitate WAS/RLAN use indoors an impact on indoor MFCN usage would actually be intended.

Study A4 (see section 4.14) assesses the spectral efficiency of MFCN as a result of reduced MFCN BS *e.i.r.p.* Based on a site-specific ray tracing and model of buildings in the studied area it indicates that a reduction of 6 dB in BS *e.i.r.p.* from 83 dBm/100 MHz to 77 dBm/100 MHz reduces the median spectral efficiency by approximately 15%. A reduction to 71 dBm/100 MHz reduces the median cell throughput by approximately a further 22 percentage points, and the MFCN cell shrinks with no transmissions possible at the cell edge. At 65 dBm/100 MHz *e.i.r.p.* the median cell throughput degrades by 57%, and at 59 dBm/100 MHz by 76% relative to the 83 dBm/100 MHz. Note that the cell median throughput corresponds to a mix of both indoor and outdoor users and represents the cell capacity.

Study C11 (see section 4.16), addressing downlink and assuming uplink coverage is provided, assuming an RSRP threshold of -112 dBm for downlink coverage and a throughput calculation method that is based on MIMO and 3GPP UMa channel modelling, concludes that reducing the BS *e.i.r.p.* presents a coverage and capacity degradation to MFCN. Coverage likelihood for cell-edge users (assuming all are at 1.5 m above ground and in NLOS conditions) decreases by 55% for a 10 dB reduction in BS *e.i.r.p.* from 82 dBm/100 MHz, and by 95% when reducing to 57 dBm/100 MHz. Cell average throughput degradation, considering indoor and outdoor users, is 31% (comparing 72 dBm/100 MHz with respect to 82 dBm/100 MHz), and 78% (when reducing to 57 dBm/100 MHz from 82 dBm/100 MHz).

Study A5 (see section 4.20) has shown that if a mobile network operator deployed a large number of BSs across cities and towns to compensate for the coverage loss resulting from a 15 dB and 25 dB reduction in BS *e.i.r.p.*, the interference to WAS/RLAN would only be reduced by 3 and 6 dB, respectively, compared to a non-densified MFCN deployment.

A sensitivity analysis in study D10 (section see 4.4) also examines the case where the IEEE 802.11bc signals are transmitted by MFCN BSs via traffic beams (rather than broadcast beams), and furthermore quantifies the impact on the downlink SINR and throughput of MFCN UEs as a result of transmissions by nearby WAS/RLAN equipment which have failed to detect the presence of MFCN. This sensitivity analysis indicates that with a MFCN BS *e.i.r.p.* of 82 dBm/80 MHz, the emissions from indoor WAS/RLAN equipment which are subject to the IEEE 802.11bc cross-technology signalling mechanism would reduce the MFCN downlink throughput to zero in around 30% of indoor locations within the MFCN cell, up from 6% in the absence of WAS/RLANs. Moreover, with the MFCN BS *e.i.r.p.* reduced to 57 dBm/80 MHz, MFCN downlink throughput would be reduced to zero in around 55% of indoor locations within the MFCN coverage area (i.e. an MFCN cell), up from around 35% in the absence of WAS/RLANs.

Study B3 (see section 4.10) suggests that MFCN UL capacity is reduced by only 5% as a result of WAS/RLAN transmissions and therefore cross-technology signalling may not be required.

6.3.4 Considerations related to coverage/capacity degradations

The significance of the degradations described in sections 6.3.1, 6.3.2 and 6.3.3 depends on a number of additional considerations related to the deployment of MFCN and WAS/RLAN usage in the Upper 6 GHz band. These considerations should be further examined. Examples of these considerations are:

- If MFCN deployments in the Upper 6 GHz band are assumed to provide:
 - both outdoor and indoor coverage/capacity; or
 - mostly outdoor coverage/capacity.
- The associated user requirements for Quality of Service, including in the uplink (which may also depend on whether lower frequency layers can be aggregated to support indoor coverage or the uplink throughput);
- Whether the Upper 6 GHz band is assumed to support the launch of MFCN 6G deployments;
- Whether the Upper 6GHz band is assumed to be an additional capacity layer for all MFCN scenarios;
- Whether the Upper 6 GHz band is assumed to be an additional capacity layer for all WAS/RLAN scenarios, including for enterprise uses;
- Whether co-channel MFCN UEs and WAS/RLAN equipment are likely to be closely located and transmitting at the same time and therefore would cause interference to each other in practice;
- The level of densification to compensate for an e.i.r.p reduction and achieve the same level of indoor and/or outdoor coverage related to the existing 3.5 GHz macro-cell deployments;
- The feasibility and availability of interworking between MFCN operators and WAS/RLAN in different configurations (residential, corporate, etc.) to offload MFCN indoor data traffic to WAS/RLAN networks instead;
- BFWA, as the fixed component of MFCN, and MFCN mobile broadband are expected to be deployed in the same area. This Report does not assess shared use between MFCN BFWA customer-premises equipment (CPE) and WAS/RLAN.

6.4 MFCN DOWNLINK/UPLINK ISSUES AND INFORMATION FROM FIELD TRIALS

Comparison of link budgets between 3.5 GHz and 6 GHz are given in section 5 along with some information on trials which used 3.5 GHz macro-cell locations for transmissions in the Upper 6 GHz.

When comparing the relative characteristics between 3.5 GHz and Upper 6 GHz, it was found that Upper 6 GHz had between 8.5 and 10 dB additional loss in the link budget depending on the scenario. This could be compensated to some degree by 4-9 dB of additional gain from increased elements in the MFCN BS antenna and a doubling of antennas in the UE (if form factors allow). Uplink waveform switching and higher UE power classes could also help offset the uplink degradation, alternatively carrier aggregation with lower bands could help.

A number of field trials have been conducted using prototype Upper 6 GHz equipment which indicated what could be achieved with Upper 6 GHz at high power.

In Germany, one trial using 3.5 GHz macro sites demonstrated at 72 dBm/80 MHz MFCN BS *e.i.r.p.* an Upper 6 GHz outdoor cell range of 500 m was possible. Outdoor throughputs up to 1.2 Gbit/s and indoor throughputs up to 535 Mbit/s were achieved in good radio conditions with line-of-sight between the MFCN BS and UE.

Similar cell ranges were achieved by another trial in Germany which used a MFCN BS *e.i.r.p.* of 72 dBm/100 MHz resulting in a downlink throughput of 2.8 Gbit/s outdoors in good radio conditions with line of sight between the MFCN BS and UE in a 100 MHz channel. An indoor UE terminal at 170 and 240 m from the BS achieved between 500 and 1300 Mbit/s in NLOS conditions with a building entry loss of 21 dB. It was observed that, in a real network implementation where 6 GHz is aggregated with lower frequency bands, downlink service may be available at lower RSRP levels, assuming that uplink uses other bands with better signal propagation.

A trial in Espoo, demonstrated that an Upper 6 GHz standard macro-cell with a 128 antenna-port BS AAS could match the performance of a 3.5 GHz cell with a 64 antenna-port BS AAS up to a distance of 650 m along a railway track from the rooftop site. At 250 m, the uplink performance with a bandwidth of 60 MHz in the Upper 6 GHz was 104 Mbit/s compared to 118 Mbit/s in the 3.5 GHz band.

A trial examined the indoor performance achievable from Upper 6 GHz with a macro-cell BS with a *e.i.r.p.* of 79 dBm (over 100 and 200 MHz bandwidths) in an urban-type environment. It indicated that a 3 dB reduction in BS *e.i.r.p.* resulted in a mean throughput reduction of around 61% across the 20% poorest indoor coverage locations tested. Outdoor results were not reported.

A trial in Dallas showed the presence of interference from a WAS/RLAN LPI device to MFCN when the LPI AP and MFCN UE were separated by 4 and 13 m in indoor locations. It was determined that LPI beacon and FILS management frames transmissions (every ~102 ms and ~20 ms respectively), which do not carry data, have an impact on the performance of MFCN downlink while the router is ON, compared to while the router is OFF, degrading the mean throughput down from 130 Mbps by 10% at the 13 m distance, and down from 100 Mbps by 20% at the 4 m distance. In addition, impact on performance metrics was observed in the UE measurement reports to the BS, i.e. RSRP, RSRQ and SINR measurements. This corroborates that, when LPI AP and MFCN UE are in similar geometries as in the trial, a WAS/RLAN AP with a low RF activity factor (0.86% in this trial) would cause interference to MFCN DL with a similar throughput reduction as observed in this trial.

6.5 ISSUES FOR FURTHER CONSIDERATION INCLUDING BAND SPLIT APPROACHES

6.5.1 Potential band split approaches and their development

As discussed in section 6.1, where full power MFCN BS *e.i.r.p.* is assumed, there is likely to be very limited indoor locations (as low as 20% depending on the study assumptions) and no outdoor locations where WAS/RLAN use is possible within the same geographical area as MFCN. On the other hand, where reduced MFCN BS *e.i.r.p.* is assumed, it can be seen in section 6.3 that this negatively impacts MFCN coverage and capacity including in particular for indoor MFCN uses.

Therefore, in order to enable full power MFCN BS and WAS/RLAN use in the Upper 6 GHz band, additional frequency or geographical separation between MFCN and WAS/RLAN may be considered.

This Report identified as a potential approach (see section 3.3) the option of a frequency separation (i.e., a band split) combined with a potential new sharing mechanisms such as enhanced detection techniques (section 3.4), which may also support sharing in both portions of the spectrum or one portion of the spectrum:

- A band split: where the band would be segmented between WAS/RLAN (likely the lower part as it is adjacent to existing WAS/RLAN use in the Lower 6 GHz band) and MFCN (likely the upper part), enabling each application to have access to a different portion of the Upper 6 GHz band (alongside incumbents);
- Implementing sharing in both portions: where additionally to a band split, each application could opportunistically access the portion of the band assigned to the other application, provided that it does not cause undue interference to the other application. It may be particularly beneficial in geographical areas (or parts of areas) where only one application is present due to incumbents, demand in that area or deployment timescales of the assigned application;
- Implementing sharing in one portion only: where potential shared use occurs in only one of the portions of spectrum described above, while the other remains assigned to only one of the applications;

In each of the listed cases, sharing between these applications and incumbents should be considered, as appropriate.

Any practical implementation of any of the above band split options has not been analysed in this Report and requires further consideration. In particular, it has not been possible to consider the size of each portion of the band split nor where the frequency boundary between WAS/RLAN and MFCN should be as this would require knowledge of results of further work on:

- The spectrum needs in the Upper 6 GHz for MFCN and WAS/RLAN;
- Results of studies on the coexistence of both applications with incumbents such as the Radio Astronomy Service (RAS) and Fixed Links in the Upper 6 GHz band which are subject to a further ECC Report.

Concerning enhanced detection techniques explored in this Report and mentioned also in this section which aim to reduce the risk of interference between the two applications, further studies may be needed with regard to band split options to assess the impact of:

- the various technology-specific implementations of enhanced detection techniques based on SSB, IEEE 802.11bc broadcast or on-off keying and their performance considering the dynamic nature of the radio propagation channel;
- these techniques on changing availability for the relevant application over time, either WAS/RLAN (WAS/RLAN detects MFCN) or MFCN (MFCN detects WAS/RLAN), and consequences such as standardisation efforts, user experience (WAS/RLAN availability) or MNO investment (MFCN operation);
- how the performance and QoS (e.g. latency, jitter, channel availability based on density and area of deployment) of both applications could vary over time as a result;
- MFCN opportunistic operation in the portion of spectrum assigned to WAS/RLAN.

6.5.2 Interworking between MFCN and indoor WAS/RLAN

Interworking between MFCN and WAS/RLAN offers a potential solution for offloading some MFCN indoor data traffic. By utilising a WAS/RLAN access point, this approach can enhance indoor capacity for MFCN subscribers. While standardisation efforts from both the WAS/RLAN and MFCN communities have already resulted in several demonstrators, seamless roaming mechanisms between these networks, among other topics, may still require further implementation efforts to support European-wide deployments. Additionally, beyond spectrum management, there are other challenges expected to be addressed for practical European-wide implementations of the interworking between MFCN (multi-operators and international environments) and WAS/RLAN (multi-users configuration: residential, corporate, etc.) such as cybersecurity, roaming policies, implementation costs, and commercial agreements (see section 3.2.2.1).

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