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2.3 GHz Sharing Analysis

a report from Plum Consulting

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2.3 GHz Sharing Analysis

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About Plum

Plum is an independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

About this study

This study for ComReg is on the analysis of sharing feasibility in the 2.3 GHz band.

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Executive Summary

This report for ComReg considers the compatibility and coexistence of new wireless broadband services provided by Mobile/Fixed Communications Networks (MFCN) and the existing Rurtel service, operated by Eir in the 2.3 GHz band, by examining the potential for interference from a co-channel and adjacent channel perspective. This report also investigates the impact of MFCN base stations operating in the 2.3 GHz band adjacent to Wireless Local Area Network (WLAN) devices operating in the 2.4 GHz band (2400 – 2483.5 MHz).

The coexistence analysis presented in this report is based on deriving interference contours around RurTel receivers for an assumed set of receiver interference threshold values. The modelling assumptions are set out in Appendix A. Based on the analysis results, recommendations are made to ComReg to better inform its proposed Multi Band Spectrum Award and the need for additional technical licence conditions to facilitate the effective rollout of wireless broadband services in the 2.3 GHz band.

Sharing between MFCN and RurTel

The analysis presented in this report identified potential for co-channel interference over large geographic areas around the locations of the RurTel base station receivers. Therefore, for MFCNs to be deployed in areas surrounding RurTel base station receivers, Plum recommends that ComReg define a coordination procedure to ensure co-existence between proposed MFCN deployments and existing RurTel networks. The size of coordination areas varies with the assumed interference threshold.

However, noting that co-channel interference impacts the deployment of MFCN over large geographic areas, Plum understands that ComReg, as part of its proposed award process, is considering the future of Eir's RurTel network in the 2.3 GHz band. In the event that the RurTel network is reduced or retired from the 2.3 GHz band, the requirement for a coordination procedure should be assessed to reflect any changes.

In the case of adjacent channel co-existence, while noting that uncertainty exists regarding the RurTel receiver performance (e.g. receiver selectivity) and link budgets, Plum is of the view that adjacent channel coexistence between MFCN and Rurtel networks could be feasible without the implementation of coordination areas for most deployment scenarios.

Sharing between MFCN and WLANs

ECC Decision (14)02 specifies harmonised technical conditions in the form of BEMs to facilitate coexistence between MFCN base stations deployed in the 2.3 GHz band and systems (i.e. WLANs) operating above 2.4 GHz. These include implementing:

- a reduced in-block EIRP limit for the band 2390 – 2400 MHz, and
- additional baseline BEM out-of-band EIRP limits.

In addition to ECC Decision (14)02, the UK regulator (Ofcom) conducted a number of extensive studies on the coexistence of WLAN and MFCN base stations. The studies concluded, among other things, that the number of affected devices is expected to be low and, in many cases, potential coexistence issues could be mitigated by moving the WLAN device to an area less susceptible to MFCN interference. In addition, Ofcom noted that new WLAN devices are equipped with dual-band capabilities which use both 2.4 GHz and 5 GHz as well as in-device filtering to avoid harmful interference.

Taking into account the outcome of extensive studies performed in the UK, Plum is of the view that in implementing the specific limits outlined in ECC Decision (14)02 for the protection of WLAN devices, adjacent band coexistence between MFCN and WLANs is feasible without additional implementation measures from ComReg.

1 Introduction

ComReg, as part of its proposed Multi Band Spectrum Award (MBSA), is proposing to award the 2.3 GHz band (2300 – 2400 MHz) for use by Mobile/Fixed Communications Networks (MFCN) for the provision of wireless broadband services. This report considers the technical feasibility of new wireless broadband services provided by MFCN sharing the 2.3 GHz band with the existing RurTel[1] service, operated by Eir, and examines the potential for interference from a co-channel and adjacent channel perspective. This report also examines the potential impact of MFCN base stations operating in the 2.3 GHz band with adjacent Wireless Local Area Network (WLAN) devices operating in the 2.4 GHz band (2400 – 2483.5 MHz).

The coexistence analysis presented in this report is based on the assumed modelling parameters set out in Appendix A. Based on this analysis, recommendations are made to ComReg to better inform its proposed Multi Band Spectrum Award and the need for additional technical licence conditions to facilitate the effective rollout of wireless broadband services in the 2.3 GHz band.

[1] RurTel is a wireless point-to-multipoint telephony solution to geographic areas of Ireland such as Kerry, Galway and Donegal which are difficult to provide service to by other means.

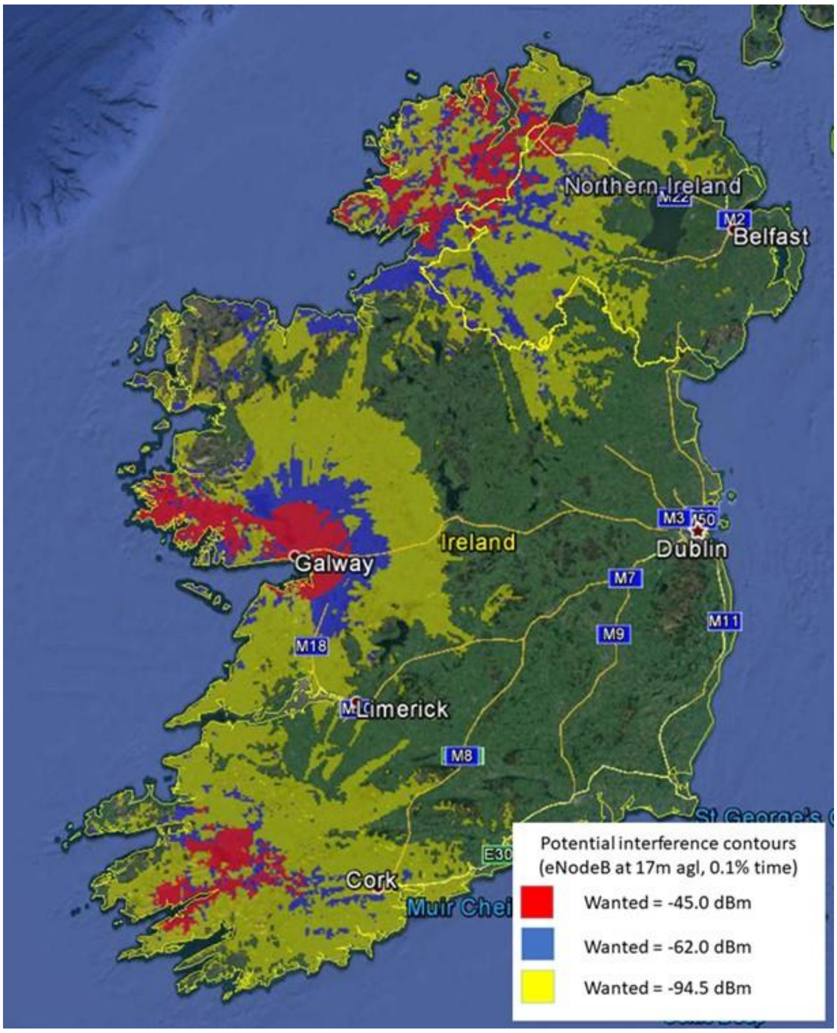
2 Sharing between MFCN and RurTel

The assumed modelling parameters, available in Appendix A, are derived from data provided by ComReg. There are 35 RurTel licences currently operational providing 47[2] operational point-to-multipoint links. The results illustrate the potential co-channel interference from MFCN wide-area base station transmitters into the currently operational RurTel base station receivers. Further analysis is conducted to investigate the potential impact of adjacent band coexistence between the same.

2.1 Co-channel coexistence between MFCN and RurTel base stations

The calculated co-channel composite interference contours are shown in Figure 2.1[3] for each assumed interference threshold. These thresholds are based on protecting three RurTel Base Stations (BS) received power levels against interference from an MFCN base station transmitter. Specifically, the three power levels are -45 dBm (maximum), -62 dBm (median) and -94.5 dBm (minimum)[4] at the RurTel base station receiver.

Figure 2.1: Composite Interference Contours Calculated for all RurTel BS Receivers (0.1% of time)



[2] Since RurTel is a point-to-multipoint system, its licence can include more than one link.
[3] Large scale maps showing coverage in Donegal, Galway and Kerry are given in Appendix B
[4] Described in Appendix A.3, Table A.2

Large scale maps showing coverage in Donegal, Galway and Kerry are given in Appendix B.

The results in Figure 2.1 show that if a minimum Rurtel BS receive level is assumed (i.e. -94.5 dBm), the co-channel deployment of an MFCN base station using the lower 2.3 GHz band (2305-2325 MHz) in the yellow area could impact Rurtel BS receivers. Similarly, if the median (i.e. -62 dBm) and maximum (i.e. -45dBm) receive levels are assumed then deployment of MFCN in the blue and red areas respectively could impact Rurtel BS receivers operating in those areas.

Table 2.1 below estimates the potential impact on population from the RurTel network for co-channel interference (where an asssumed wanted power level is -94.5 dBm) in each of the three areas affected. In total, the RurTel network impacts on 27% of the population, the majority of which is in the areas of Galway and Kerry.

Table 2.1: Potential RurTel Polulation Impact (Co-channel Interference)

Area	Population
Kerry	462,000
Galway	523,000
Donegal	292,000
All	1,277,000

2.2 Adjacent band coexistence between MFCN and RurTel base stations

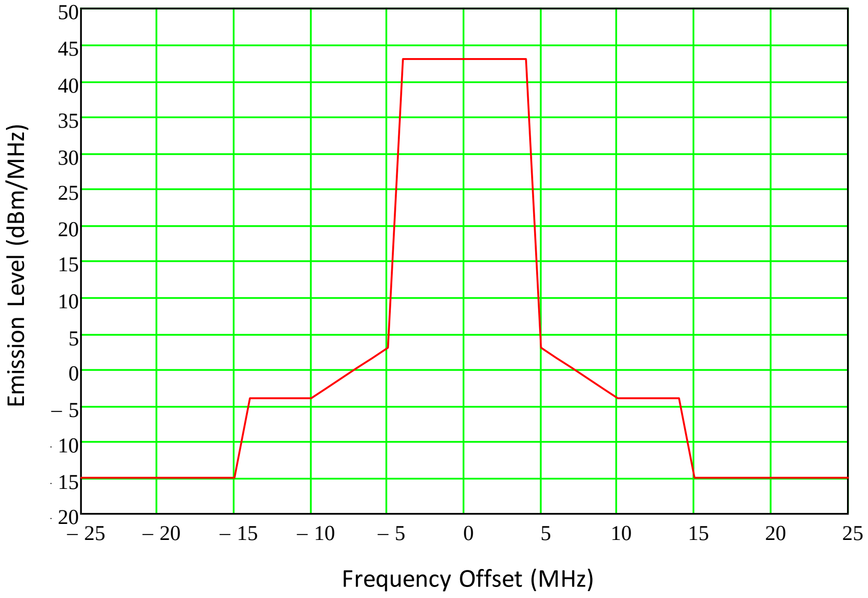
2.2.1 Implications of transmitter and receiver masks

Data related to MFCN base station transmitter and RurTel base station receiver selectivity masks are required in order to carry out the analysis of adjacent band sharing between MFCN and RurTel base stations.

MFCN base station transmitter masks are defined in 3GPP 36.104[5]. An example mask defined for wide area base stations is shown below. It is worth noting that the performance of actual transmitters is expected to be better than the values shown in the mask (i.e. lower out of band emission levels).

[5] https://www.etsi.org/deliver/etsi_ts/136100_136199/136104/14.03.00_60/ts_136104v140300p.pdf

Figure 2.2: MFCN Base Station Transmitter Mask – Power into Antenna (3GPP 36.104 V15.3.0, Wide Area, Category B, Option 1, Band 40, Bandwidth >= 5MHz)



Assumptions are necessary to provide a coexistence analysis as there is no available data related to RurTel base station receiver selectivity.

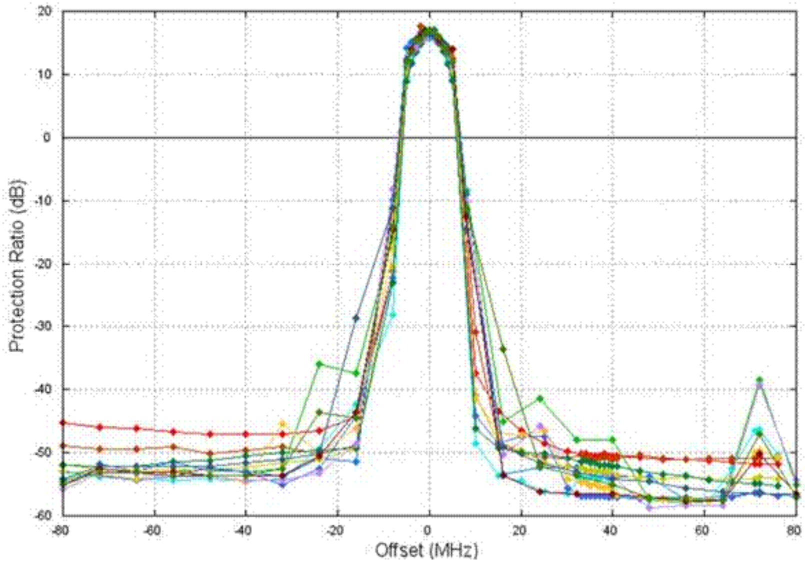
Our understanding is that the RurTel system is a Time-Division Multiple Access (TDMA) point to multipoint fixed radio network designed to support digital radio telephony links. Historical ETSI specifications EN 300 636 and EN 301 373 provide system characteristics for fixed point to multipoint TDMA and FDMA digital radio systems designed for operation in 1 – 3 GHz. These specifications are superseded by EN 302 326 which defines harmonised technical specifications for digital multipoint radio equipment.

According to EN 302 326-2[6], for TDMA equipment operating in 1 – 3 GHz, the difference between co-channel and adjacent channel interference rejection limits is 23 dB. The context of this ETSI specification is not known, however, and this selectivity performance seems implausibly poor for a practical system.

As a counter-example, measurements made[7] of the susceptibility of consumer DTT receivers to interference from LTE base stations show an adjacent channel selectivity (ACS) of at least 50 dB.

[6] Table 9 (page 34) and Table 11 (page 36) in https://www.etsi.org/deliver/etsi_en/302300_302399/30232602/01.02.02_60/en_30232602v010202p.pdf
[7] "Measured DVB-T Protection Ratios in the presence of Interference from White Space Devices", BBC R&D white paper 226, April 2012 in https://www.bbc.co.uk/rd/publications/whitepaper226

Figure 2.3: Measurements of DTT receiver selectivity (source: BBC)



A document[8] which is slightly more contemporary with the deployment of the RurTel system examines the selectivity requirements of 3G CDMA receivers. This document cites an adjacent channel selectivity requirement of 33 dB, coupled with a coding gain of 25 dB, giving an overall adjacent channel rejection of 58 dB.

A technical article[9] relating to software-defined radio design quotes adjacent channel selectivity figures for GSM and LTE systems in the range of 40 – 50 dB.

Based on these figures we consider a plausible value for the adjacent band selectivity of the RurTel system is in the order of 50 dB. Making a simplifying assumption that receiver response dominates and there is a flat receiver response at all greater frequency separations between MFCN and RurTel operating channels, the effective MFCN EIRP value is 71 dBm – 50 dB = 21 dBm.

Plots of the composite interference contours are given below in Figure 2.4 and Figure 2.5 for a 50 dB adjacent band selectivity value, and for a more pessimistic value of 40 dB.

2.2.2 Adjacent band analysis

The calculated composite interference contours are shown in the Figure 2.4 (50 dB ACS) and Figure 2.5 (40 dB ACS) for the assumed interference thresholds. Large scale maps of areas including Donegal, Kerry and Galway are illustrated in Appendix B.

[8] "RF Receiver Requirements for 3G W-CDMA Mobile Equipment", Jensen, O.K., et al, Microwave Journal, 43(2), February 2000 in https://www.microwavejournal.com/articles/2877-rf-receiver-requirements-for-3g-w-cdma-mobile-equipment.

[9] "https://www.nutaq.com/wp-content/uploads/2017/12/3GPP-Radio-Prototyping-Using-Radio420X.pdf"

Figure 2.4: Adjacent Band Composite Interference Contours Calculated for all RurTel BS Receivers (0.1% of time, 50 dB ACS)

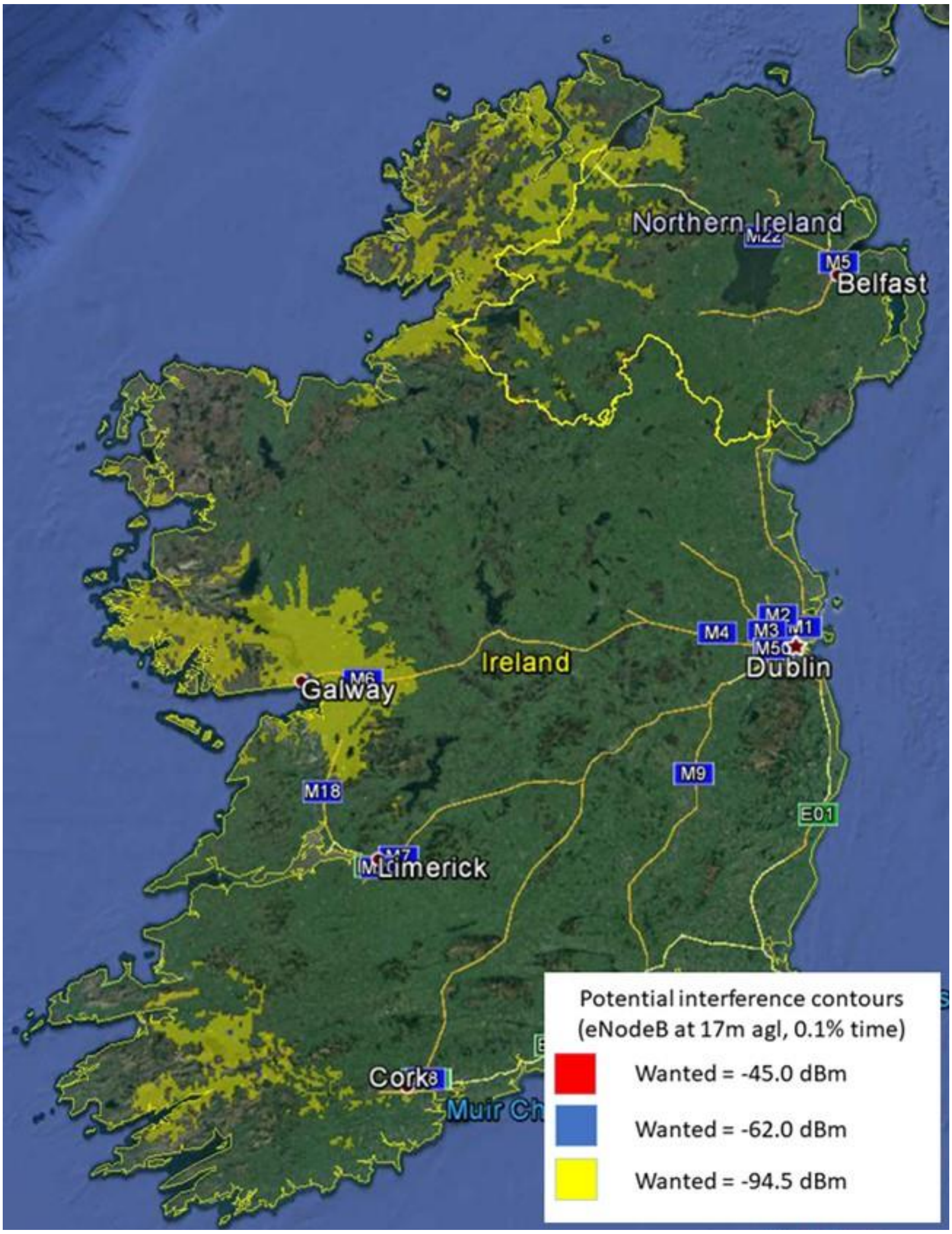
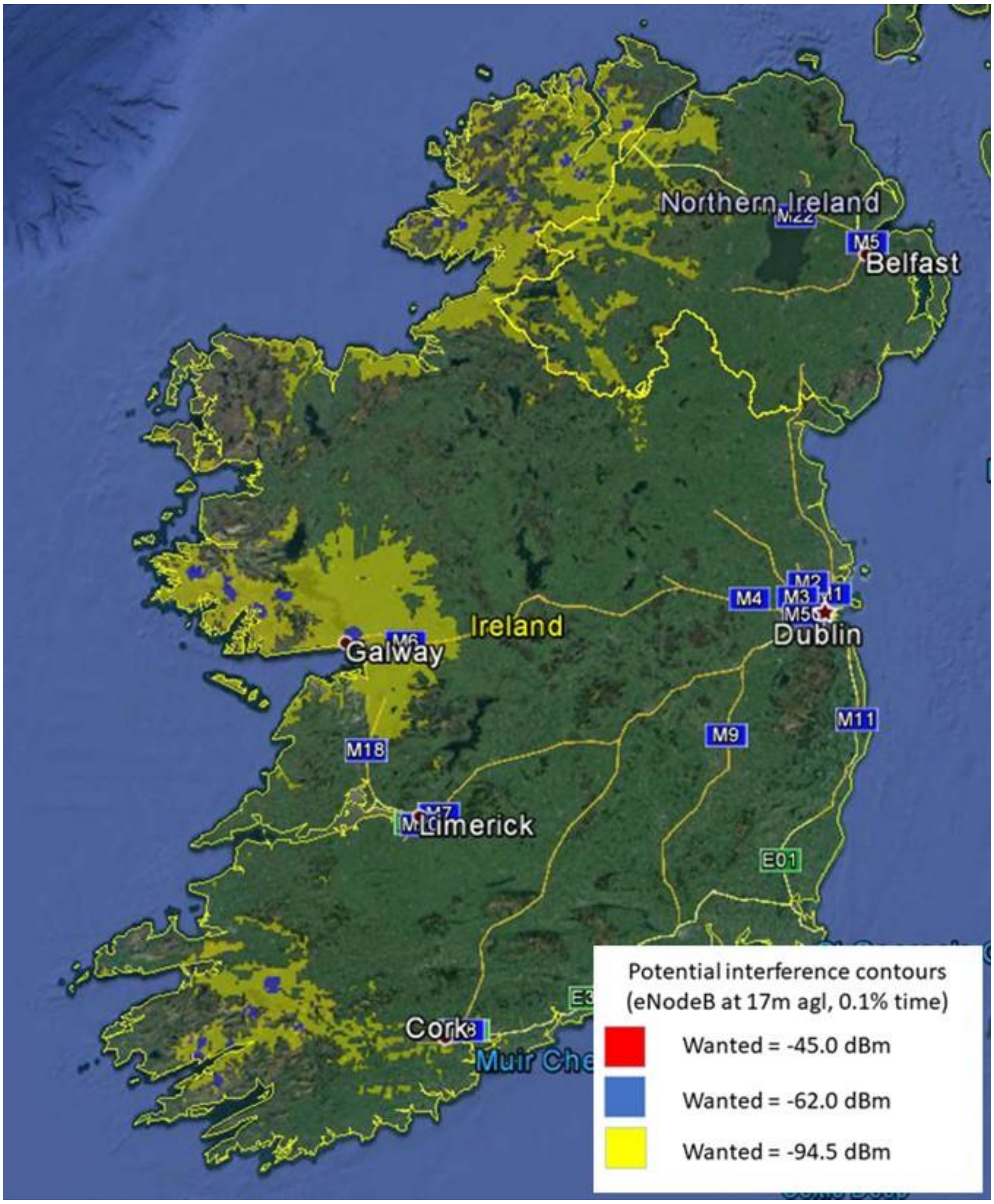


Figure 2.5: Adjacent Band Composite Interference Contours Calculated for all RurTel BS Receivers (0.1% of time, 40 dB ACS)



It is clear from the above figures (see also Appendix B for large scale maps) that adjacent channel interference will only be significant in cases where the wanted RurTel signal is close to the noise floor i.e. the minimum (-94.5 dBm). In the case of median (i.e. -62 dBm) or higher (i.e. -45 dBm) wanted signal levels, any possible interference effect would be limited to LTE base stations located in pixels immediately adjoining the RurTel receiver site.

2.3 Implications of MFCN user terminals

EIRP levels associated with MFCN user terminals are much lower than those associated with MFCN base stations (e.g. 68 dBm/5MHz vs. 25 dBm/5MHz according to ECC Decision (14)02)[10]. User equipment are also likely to be deployed at lower heights within cluttered locations compared to base stations. Therefore, the coordination areas calculated for MFCN base stations should be sufficient for the protection of RurTel base stations from MFCN user terminal interference.

2.4 Summary and conclusions

This report models the interference from MFCN BSs into RurTel BS receivers. In the modelling, the composite interference areas surrounding RurTel BS receivers have been determined. These interference areas show the areas within which the deployment of MFCN base station transmitters is likely to result in the Rurtel receiver interference thresholds being exceeded.

Similarly, the adjacent channel coexistence is modelled to determine the impact on existing Rurtel base station receivers.

Co-channel co-existence between RurTel and MFCN

Based on the assumptions outlined in Appendix A, the results from the co-channel interference analysis show large areas within which the deployment of MFCN base stations is likely to exceed the assumed RurTel BS interference thresholds. To minimise the risk of interference within the calculated interference areas as depicted in Figure 2.1 and Appendix B, the deployment of MFCN BSs may require coordination between MFCN operators and Eir.

Outside of the composite interference areas, the likelihood of exceeding RurTel interference threshold can be assumed to be minimal.

Adjacent band co-existence between RurTel and MFCN

The analysis in this report also considers the potential adjacent channel interference between RurTel and MFCN base stations, based on the assumed RurTel receiver selectivity levels of 40 dB and 50 dB. The results in Figure 2.4 (50 dB ACS) and Figure 2.5 (40 dB ACS) show that the adjacent channel interference is only significant where the RurTel BS wanted power is close to the noise floor i.e. at its minimum (-94.5 dBm). In the case of median (i.e. -62 dBm) or higher (i.e. -45 dBm) wanted signal levels, any possible interference effect would be limited to MFCN base stations located in pixels immediately adjoining the RurTel receiver site.

Although there is uncertainty regarding the RurTel receiver performance, installed antenna systems and actual link budgets, adjacent channel co-existence between MFCN (below 2305 and above 2330 MHz[11]) and RurTel (operating in the band 2307-2327 MHz) is likely to be feasible in practice for most deployment scenarios without the need for any coordination.

[10] ECC Decision (14)02 defines harmonised technical conditions for the 2300 – 2400 MHz band in the form of BEMs. https://www.ecodocdb.dk/download/b02d6dab-2b58/ECCDEC1402.PDF

[11] The harmonised frequency arrangements in Annex 1 of the ECC Decision Of 27 June 2014 On Harmonised Technical And Regulatory Conditions For The Use Of The Band 2300-2400 MHz For Mobile/Fixed Communications Networks (MFCN) (ECC/Dec/(14)02), identify that there are 20 blocks of 5 MHz starting at 2300 MHz to 2400 MHz.

3 Sharing between MFCN and WLANs

ECC Decision (14)02 states that Block Edge Masks (BEMs) are required to allow coexistence between MFCN deployed in the 2.3 GHz band and systems operating above 2.4 GHz band (e.g. WLANs).

To facilitate coexistence with systems above 2.4 GHz, ECC Decision (14)02 provides for the implementation of:

- a reduced in-block EIRP limit for the band 2390 – 2400 MHz, and
- additional baseline BEM out-of-band EIRP limits.

In the 2390 – 2400 MHz band, the in-block EIRP limit is 45 dBm/5MHz (compared to a non-obligatory 68 dBm/5MHz EIRP limit defined for 2300 – 2390 MHz).

The ECC Decision defines additional baseline emission limits for frequencies above 2.4 GHz for both synchronised and unsynchronised base stations. The limits are in the form of EIRP applicable above 2403 MHz and are shown in the following table.

Table 3.1: Additional Baseline Requirements above 2403 MHz (BS BEM Out-of-band EIRP Limits)

BS EIRP	Out-of-band EIRP Limit
> 42 dBm	1 dBm/5MHz
> 24 dBm and ≤ 42 dBm	(BS EIRP – 41) dBm/5MHz
≤ 24 dBm	-17 dBm/5MHz

It is also noted that the use of power control is mandated for femto base stations to minimise adjacent band interference.

The review of relevant literature (detailed in the following sections) has indicated that the in-block and out-of-band EIRP limits included in the ECC Decision for MFCN and WLAN coexistence are based on work undertaken in CEPT FM 52. In the UK, Ofcom and the Ministry of Defence (MoD) commissioned studies on the subject. The remainder of this section presents a review of FM 52 work and detailed studies performed in the UK and identifies the key conclusions relevant to the Irish context.

3.1 Review of FM 52 work

The meeting notes of 7th FM 52[12] (May 2014) suggest that there were many comments and proposals on the adjacent band compatibility between MFCN and WLANs. After detailed discussions, which included a small drafting group, FM 52 agreed to introduce reduced in-block and additional baseline out-of-band EIRP limits.

[12] Draft minutes of the 7th meeting of PT FM52, FM 52 (14) 24 Rev1, May 2014

There is a background document[13] presented in the same meeting that provides information on the assumptions and analysis which resulted in the EIRP limits. The analysis is relatively simple and based on the principles used in ECC Report 203[14] (where BEMs for 3.5 GHz band are derived).

The in-block EIRP limit of 45 dBm/5MHz (defined for 2390 – 2400 MHz) assumes that WLAN Access Point (AP) blocking level is -40 dBm/10MHz. It is further assumed that, based on ECC Report 203, the minimum path loss between MFCN BS and WLAN AP is 70 dB (free space) and the building penetration loss is 18 dB. These values result in an in-block EIRP limit of 45 dBm/5MHz.

In the case of out-of-band EIRP limits, the key assumptions are as follows:

- WLAN Receive Bandwidth = 17.5 MHz (note that this assumption together with the first WLAN centre frequency of 2412 MHz determines the starting frequency for the out-of-band limits, i.e. 2403 MHz)
- WLAN Receiver Noise Figure = 10 dB
- WLAN Receiver Noise Floor = -91.5 dBm/17.5 MHz
- WLAN Receiver Interference Threshold = Noise Floor – 10 dB = -81.5 dBm/17.5 MHz
- Minimum Path Loss between MFCN Macro BS Transmitter and WLAN Receiver = 70 dB
- Building Penetration Loss = 18 dB
- Maximum Out-of-band EIRP for MFCN Macro BS = 6.5 dBm / 17.5 MHz = 1 dBm / 5 MHz

For MFCN micro BS, the minimum path loss is assumed to be 64 dB (based on ECC Report 203) while the assumptions relating to the remaining parameters are the same. In the case of an MFCN femto base station, the minimum path loss is assumed to be 60 dB and the wall loss is assumed to be 10 dB (based on ECC Report 203).

3.2 Review of Ofcom work

Ofcom undertook investigations and launched a consultation in February 2014 as part of the award of 2.3 and 3.4 GHz bands. The feasibility of adjacent band sharing between LTE-TDD and WLAN systems was one of the key issues examined in detail. A number of reports are currently available outlining Ofcom's activities[15]. In this section, we summarise Ofcom's work and the key conclusions.

The spectrum award in the 2.3 GHz band was limited to the 2350 – 2390 MHz band. This implies a 10 MHz guard band at the top of the 2.3 – 2.4 GHz band. Ofcom assessed the risk of interference into domestic, outdoor public, indoor public and enterprise WLAN usage through a combination of laboratory and field measurements and theoretical analysis.

3.2.1 Laboratory measurements

The tests were performed in an anechoic chamber using a simulated LTE TDD source (20 MHz downlink signal at 2380 MHz with highest duty cycle, i.e. configuration 5 defined in 3GPP TS 36.211) and 21 Wi-Fi devices. It was

[13] Coexistence between MFCN BS in the 2.3 – 2.4 GHz band and WLAN above 2.4 GHz, Annex 9 to FM 52 (14) 24, May 2014

[14] https://www.ecodocdb.dk/download/f5cd8793-5692/ECCREP203.PDF - Least Restrictive Technical Conditions suitable for Mobile/Fixed Communication Networks (MFCN), including IMT, in the frequency bands 3400-3600 MHz and 3600- 3800 MHz, Approved 8 November 2013, Corrected 14 March 2014.

[15] https://www.ofcom.org.uk/consultations-and-statements/category-1/pssr-2014

concluded that interference would be a possibility in the presence of high LTE signal levels resulting in a drop in Wi-Fi throughput. Interference was dominated by blocking rather than out-of-band emissions, i.e. interference was the result of a lack of band pass filter on the Wi-Fi front-end.

Three metrics were used to record the blocking power level:

- Throughput starts to drop,
- Throughput drops to 50% of the maximum level, and
- Throughput is below 1 Mbps.

The measured blocking levels are shown in the following table.

Table 3.2: Blocking Levels[16]

Device	Performance (based on 21 Wi-Fi devices)	Blocking Level (dBm)		
		Onset of degradation	50% throughput	1 Mbps
Access Points / Routers	Worst case	-44	-41	-38
	Median	-39	-33	-29
	Best case	-34	-26	-25
Client Devices	Worst case	-47	-42	-39
	Median	-35	-28	-27
	Best case	-11	-11	-9

As can be seen, the blocking levels vary considerably depending on the device type. Measurements also showed that moving to higher Wi-Fi channels or improving filtering on the LTE BS would not mitigate the risk of interference whereas improved filtering at Wi-Fi devices would mitigate the risk of interference.

ETSI EN 300 328 specifies a receiver blocking level of -30 dBm for a CW signal at 2395 MHz. IEEE Standard 802.11 defines 'a maximum interference power a receiver should be able to tolerate from another 2.4 GHz device which is not immediately adjacent'. This metric is the closest approximation for a blocking level. The specified level is -47 dBm. While both standards define fixed blocking levels for all modulation schemes and coding rates actual devices are expected to shift to lower modulation when they are interfered with which will mean throughput reduction at the start of blocking and a total link failure when the interference level is higher.

3.2.2 Field measurements

Ofcom performed a range of field tests to validate laboratory measurements under representative operating conditions.

Tests on routers in indoor and outdoor environments using a simulated LTE BS confirmed that blocking effects occur at similar levels to those found in laboratory measurements. The position of the router relative to the LTE

[16] Technical Coexistence Issues for the 2.3 and 3.4 GHz Award (Annexes 7 - 13), Ofcom, February 2014, (https://www.ofcom.org.uk/__data/assets/pdf_file/0034/46699/annexes_7-13.pdf)

BS is found to be the key factor determining the interference power (i.e. the LTE BS antenna gain towards the router).

Tests on a client device showed that the throughput varies considerably depending on the device orientation and user position before the LTE BS was switched on. This suggested that the impact of interference might be masked by normal variability and could be mitigated by moving the affected device.

Drive tests measuring LTE signal strengths at short distances from a network of live BSs operating in the 1800 MHz band showed that LTE signal levels could be high enough to exceed some of the Wi-Fi blocking levels measured in the laboratory.

3.2.3 Theoretical analysis

Using the measured median device blocking levels corresponding to the onset of degradation at access points (i.e. -39 dBm) and client devices (i.e. -35 dBm), minimum separation distances were determined.

Table 3.3: Minimum Separation Requirements[16]

LTE Interferer	Wi-Fi Victim	LTE EIRP (dBm)	MCL (dB)	Required Separation (m)
Macro Cell at 20 m height	Access Point	67	106	220
	Client Device		102	160
Small Cell at 5 m height	Access Point	45	84	55
	Client Device		80	45
Femto Cell (using max power)	Access Point	20	59	9
	Client Device		55	5
Femto Cell (using typical power)	Access Point	10	49	3
	Client Device		45	2
Mobile Device (using max power)	Access Point	23	62	13
	Client Device		58	8
Mobile Device (using typical power)	Access Point	3	42	1
	Client Device		38	1

The results shown above are based on the following assumptions:

- Macro and small cell scenarios are based on suburban Hata model while other scenarios assume free space. In urban scenarios, distances are expected to be reduced. In femto cell scenarios where the free space path loss is assumed, the effects of wall loss are expected to reduce the calculated distances.
- Macro and small cell antenna discriminations at the elevation plane are taken into consideration. It is assumed that the victim device is within the sector boresight, i.e. no discrimination in the azimuth plane.
- No antenna discrimination is assumed for LTE mobile devices, LTE femto cells and Wi-Fi receivers.

The minimum coupling loss analysis was followed by a detailed downlink interference analysis. The analysis is based on calculating signal strengths from a population of operational LTE BSs deployed in the UK in the

2.1 GHz band. This is used as a representative reference network deployment in the 2.3 GHz band. Calculated LTE signal levels are then compared against the measured blocking thresholds at known Wi-Fi locations at a postcode level to determine the percentage of Wi-Fi devices that could be interfered with.

LTE BSs are assumed to operate with 67 dBm/20MHz (i.e. 61 dBm/5MHz which is the limit in the technical licence conditions). For the path loss calculations, the extended Hata model was used with 10 dB correction applied to account for the over-estimate of interference compared to the results of a propagation study (commissioned by Ofcom to Siradel) using ray tracing modelling in London and its suburbs. For scenarios where the victim is located indoors, building penetration loss values are assumed to be 6.9, 8.4 and 12.9 dB depending on the type and location of the Wi-Fi receiver in the building.

The table below shows the summary of detailed downlink interference analysis results for the blocking levels measured at worst, median and best performing devices. For routers/access points, it is assumed that the blocking effects occur at the onset of throughput degradation. In the case of client devices, it is assumed that the 50% drop in the throughput is a more representative metric for blocking effects to be noticed by the users.

Table 3.4: Impact of LTE BS Interference (device types)[16]

Wi-Fi Receiver Category	Total Number of Networks	Routers / Access Points (% Locations Affected)			Client Devices (% Locations Affected)		
		Worst Device	Median Device	Best Device	Worst Device	Median Device	Best Device
Domestic	17,500,000	0.2	0.1	0	0.2	0	0
Outdoor Public	4,000	9.7	6.8	4.2	7.7	1.4	0
Indoor Public	78,000	2.4	1.4	0.6	1.5	0.1	0
Enterprise	680,000	1.8	1.2	0.6	1.3	0.1	0

The impact of interference at median device for different throughput metrics is shown below.

Table 3.5: Impact of LTE BS Interference (performance metric)[16]

Wi-Fi Receiver Category	Total Number of Networks	Routers / Access Points (% Locations Affected)			Client Devices (% Locations Affected)		
		Onset	50% drop	1 Mbps	Onset	50% drop	1 Mbps
Domestic	17,500,000	0.1	0	0	0.1	0	0
Outdoor Public	4,000	6.8	3.7	1.7	4.4	1.4	1.1
Indoor Public	78,000	1.4	0.5	0.2	0.6	0.1	0.1
Enterprise	680,000	1.2	0.5	0.2	0.5	0.1	0.1

3.2.4 Ofcom's conclusions

Ofcom concluded that there may be a small number of affected Wi-Fi networks in practice based on the results of extensive studies. It is stated that '*Given that we expect the total number of affected devices to be low, and that mitigations are available in all cases, we consider that the impact of interference to Wi-Fi is limited and that no intervention in the market is necessary, as this would be disproportionate.*'

The following possible ways of mitigating the effects of interference are proposed.

- Moving devices: This may be possible when mobile device is interfering, or the client device is interfered with.
- Upgrading equipment: A wide variation in susceptibility to interference is shown. Upgrading devices may help to mitigate interference. In particular, devices with a band pass filter to reject 2.3 GHz signals will perform better.
- External receiver filters: In theory, an external filter to attenuate the interfering LTE signal is a possibility for routers / access points.
- Use of 5 GHz band: Wi-Fi devices can make use of 5 GHz band.
- Use of wired networks: This could be a viable solution if interference is significant.
- Restrictions on LTE: LTE EIRP might be limited to provide some mitigation. Filtering at LTE BS transmitter is unlikely to help as the dominant mechanism is the Wi-Fi receiver blocking.

3.2.5 Update on coexistence with Wi-Fi

Ofcom published an update[17] on the coexistence of 2.3 GHz LTE with Wi-Fi in December 2014 after analysing consultation responses. The following points are noted from the update.

- Consultation responses suggested that the impact of LTE small cell deployment might be worse than the national macro cell deployment assumed in the Ofcom's analysis. It was also suggested that the impact of LTE user equipment might have been underestimated. More real-world testing was also recommended.
- In response, Ofcom performed further technical analysis to assess the impact of interference from small cells and mobile devices using theoretical analysis, laboratory measurements and field trials.
- Laboratory measurements addressed interference from mobile devices. WLAN equipment tested included 802.11n devices and video streaming to address the points raised in the consultation regarding the new applications and high throughputs.
- Compared to the previous laboratory measurements, the new results showed that the onset of degradation occurred at the same level of interference while some devices performed better at the 50% and 1 Mbps throughput levels.
- Further laboratory measurements were performed to understand the time domain effects of uplink LTE signals. In the measurements, the simulated LTE signal (i.e. LTE configuration 2) was replaced with recorded signals from a live 2.3 GHz network (provided by Wireless TIC group) to represent light, heavy

[17] https://www.ofcom.org.uk/__data/assets/pdf_file/0019/36037/updated-analysis.pdf

and continuous use. The results showed that some Wi-Fi devices performed better in the presence of interference and in some cases sufficiently high interference levels could not be generated at 3 metres distance from the Wi-Fi device which indicates the Wi-Fi device resilience to interference in practice. For some devices there was no noticeable improvement against interference compared to the simulated uplink signal.

- Ofcom undertook a field trial in conjunction with Sky and 7Signal in Victoria Station in London to assess the impact of interference from a base station simulator by using passive Wi-Fi monitors deployed across the station. Tests were conducted over two weeks on four days. The result showed that there was no noticeable disruption to the Wi-Fi network. It was also observed that the 2.4 GHz band was congested before the LTE transmitter was on and there was no significant reduction in throughput when the interference source was active.

- On the issue of potential for interference from small cells, Ofcom concluded that outdoor small cells are likely to be deployed as in-fill in urban areas. Their interference range is much smaller compared to macro cells (e.g. 8 metres vs. 220 metres) so interference could be avoided through careful deployment. Similarly, it is argued that, based on the trials, the interference potential from indoor pico cells and femto cells is low unless they are located at very short distance from Wi-Fi and careful siting could be used to solve any issues.

The updated document refers to a Wi-Fi alliance study[18] which also indicated that blocking is the dominant mechanism and performance of Wi-Fi devices varies considerably. It was stated that one of the Wi-Fi devices performed better as it included a filter.

A further study[19] referred to in the document is by Telefonica in conjunction with OptiWi-Fi where indoor trials were conducted. Tests looked at the impact of indoor pico-cell base station and mobile devices to Wi-Fi access points and client devices. The conclusion was that there was a minimal impact on Wi-Fi when the LTE device was at a close range. For example, LTE pico cell base station at 5 m from an access point caused 10% throughput reduction. LTE mobile device at 0.5 m from a Wi-Fi device caused less than 10% throughput reduction.

Ofcom engaged with a total of 36 organisations across the mobile and Wi-Fi industry (equipment manufacturers, mobile operators and ISPs) to improve their understanding of key issues. It was argued that manufacturers are aware of the potential degradation due to signals from adjacent bands (both 2.3 and 2.6 GHz) and new devices are manufactured in light of this awareness. Almost all new Wi-Fi devices are also capable of using the 5 GHz band – some able to switch automatically. Ofcom stated that '*We note that appropriately filtered 2.4 GHz Wi-Fi devices are not at risk of degradation - and that new equipment is much less likely to be affected by interference because of market developments already well underway (5 GHz dual band capability; in-device filtering etc.). The longer it takes for 2.3 GHz deployment to spread, the less the impact will be for consumers because of the normal replacement of older equipment*.'

In terms of international comparisons, Ofcom's international engagement with operators and regulators in South Korea, USA, Saudi Arabia, Finland and Portugal suggested no reported evidence of interference between 2.3 GHz mobile systems and Wi-Fi. In China, deployments are indoor only small cells to avoid interference into radars and there are no reports of significant interference – a precautionary approach has been adopted to the siting of equipment. Furthermore, Mobile WiMAX deployment in 2.3 GHz band in Australia did not cause any reported interference into Wi-Fi devices.

[18] LTE band 40 desensitization of Wi-Fi devices - Technical note, Steve Shearer, Wi-Fi Alliance, October 2014
[19] https://www.ofcom.org.uk/__data/assets/pdf_file/0025/73537/optiwi-fi_report_2_3_and_2_4_ghz_coexistence.pdf

Overall, Ofcom concluded that '*Our additional work outlined above suggests that the risk of interference is no higher than in the results set out in the February 2014 consultation*.'

3.2.6 Information memorandum

In its information memorandum[20] (published in July 2017), Ofcom stated that '*Our technical testing suggests the [interference] risk is very low in practice. If it occurs, it is likely to result in a drop in Wi-Fi throughput which may not be noticed by many users. We have not considered it necessary to apply specific measures to protect Wi-Fi, apart from restrictions on base station emissions above 2403 MHz, in line with ECC Decision (14)02. However, our statement of May 2015 noted that Ofcom would assist internet service providers (ISPs) in gathering information about LTE roll-out, subject to respecting commercial confidentiality, if this proves necessary. Under the 2.3 GHz and 3.4 GHz licence conditions, licensees are required to retain certain information in relation to their radio equipment and to provide it to Ofcom if requested*.'

Furthermore, in relation to femto cells, Ofcom stated that '*We will encourage manufacturers of 2.3 GHz femto-cell equipment to include advice in packaging and/or installation guides on appropriate separation distances from Wi-Fi routers. The advice could be in the form of labels on equipment. This practice is in line with existing advice provided by operators who supply 2.1 GHz femto-cells. We also encourage the inclusion of plugs with long cables in femto-cell packaging*.'

3.3 UK MoD work

Plum (as part of a consortium led by CGI) provided technical support for UK MoD in assessing the adjacent band interference from LTE BSs and MSs into WLANs.

The modelling made use of WLAN protection ratio measurements (C/I) performed on commercial and domestic access points. It was assumed that WLAN receivers were operating in the first channel centred at 2412 MHz at a wanted power level 20 dB above the minimum usable signal (MUS) level which is measured at 1 Mbps throughput. The LTE signal was assumed to be 20 MHz wide and centred at 2380 MHz.

Several scenarios were analysed to determine minimum separation distances required to protect the WLAN access point receivers from LTE BS / MS interference. This was followed by statistical modelling aimed at deriving interference probabilities.

Minimum separation requirements were determined for outdoor, indoor and outdoor to indoor interference scenarios by using the Extended Hata model implemented in CEPT SEAMCAT.[21] The results are shown below.

[20] https://www.ofcom.org.uk/__data/assets/pdf_file/0030/81579/info-memorandum.pdf

[21] SEAMCAT is a software tool, based on the Monte-Carlo simulation method, which is developed within the frame of CEPT. The tool allows statistical modelling of different radio interference scenarios for performing coexistence studies between wireless systems operating in overlapping or adjacent frequency bands. https://www.cept.org/eco/eco-tools-and-services/seamcat-spectrum-engineering-advanced-monte-carlo-analysis-tool

Table 3.6: Minimum Separation Requirements[22]

Separation Distances		
WLAN Receiver	Distance	Notes
Outdoor Scenario		
Commercial Use Access Point	105 m	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -31 dB. Interference threshold is therefore (-67) – (-31) = -36 dBm. WLAN RX is at 3 metres height and LTE BS TX is at 20 m height. LTE BS antenna gain is 18 dBi and WLAN RX antenna gain is 0 dBi.
Domestic Use Access Point	91 m	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -35 dB. Interference threshold is therefore (-67) – (-35) = -32 dBm. WLAN RX is at 3 metres height and LTE BS TX is at 20 m height. LTE BS antenna gain is 18 dBi and WLAN RX antenna gain is 0 dBi.
Indoor Scenario		
Commercial Use Access Point	9 m (FSPL) 5.1 m (SEAMCAT Indoor Model)	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -31 dB. Interference threshold is therefore (-67) – (-31) = -36 dBm. LTE MS TX (at 1.5 m height) and WLAN RX (at 2 m height) are located indoors. Antenna gains are 0 dBi.
Domestic Use Access Point	5.7 m (FSPL) 4 m (SEAMCAT Indoor Model)	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -35 dB. Interference threshold is therefore (-67) – (-35) = -32 dBm. LTE MS TX (at 1.5 m height) and WLAN RX (at 2 m height) are located indoors. Antenna gains are 0 dBi.
Outdoor to Indoor Scenario		
Commercial Use Access Point	71 m	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -31 dB. Interference threshold is therefore (-67) – (-31) = -36 dBm. WLAN RX is at 2 metres height (located indoors) and LTE BS TX is at 20 m height (located outdoors). LTE BS antenna gain is 18 dBi and WLAN RX antenna gain is 0 dBi. 10 dB building penetration loss is assumed.

[22] https://www.ofcom.org.uk/__data/assets/pdf_file/0021/74613/lte_into_wi-fi_additional_analysis.pdf

Separation Distances		
WLAN Receiver	Distance	Notes
Domestic Use Access Point	64 m	WLAN RX wanted power is -87 dBm + 20 dB = -67 dBm, PR is -35 dB. Interference threshold is therefore (-67) – (-35) = -32 dBm. WLAN RX is at 2 metres height (located indoors) and LTE BS TX is at 20 m height (located outdoors). LTE BS antenna gain is 18 dBi and WLAN RX antenna gain is 0 dBi. 10 dB building penetration loss is assumed.

SEAMCAT simulation models were developed to derive interference statistics for each scenario examined under single entry interference analysis.

SEAMCAT simulation runs were based on Monte Carlo trials. In each trial, interfering and victim system transmitters / receivers were randomly located within the simulation area and, wanted and interfering signal powers were calculated at the victim receiver. Using these power levels, interference statistics in the form of a C/N+I cumulative distribution function were derived over a number of trials simulated. This was then compared against the protection ratio to determine the probability of interference.

Interference probabilities are shown for WLAN ranges calculated for minimum wanted signal levels set to MUS and MUS+20 dB.

Table 3.7: Interference Probabilities (SEAMCAT Modelling)[22]

	MUS (dB)		MUS + 20 (dB)	
Interference Scenario	WLAN Range (m)	Interference Probability	WLAN Range (m)	Interference Probability
LTE BS interference into Commercial Use Access Point (Outdoor)	70	12.1%	50	4.5%
LTE BS interference into Domestic Use Access Point (Outdoor)	70	8.3%	50	2.4%
LTE MS interference into Commercial Use Access Point (Indoor)	20	3.9%	10	1.3%
LTE MS interference into Domestic Use Access Point (Indoor)	20	2.6%	10	0.7%
LTE BS interference into Commercial Use Access Point (Outdoor to Indoor)	20	4.3%	10	0.7%
LTE BS interference into Domestic Use Access Point (Outdoor to Indoor)	20	2.9%	10	0.4%

In the study, the measurements showed that there was a small change in protection ratio with frequency offset. This indicated that blocking (i.e. the main LTE interfering signal entering through the WLAN selectivity skirt) rather than in-band interference (i.e. LTE out-of-band emissions falling in the WLAN receiver pass band) was the dominant factor.

3.4 Summary and conclusions

The implications of adjacent band interference from MFCN into WLANs were investigated in CEPT. It was decided that a reduced in-block EIRP limit applicable between 2390 – 2400 MHz and additional baseline BEM out-of-band EIRP limits applicable above 2403 MHz would enable adjacent band coexistence between MFCN and WLANs. The work underpinning these limits was undertaken in FM 52 and based on the principles adopted in ECC Report 203 where BEMs for the 3.5 GHz band are derived. The limits are part of ECC Decision (14)02 which outlines harmonised technical conditions for the 2300 – 2400 MHz band.

In the UK, Ofcom commissioned a considerable number of studies involving laboratory measurements, field trials and theoretical modelling prior to the award of licences in the 2350 – 2390 MHz band. The studies established that the dominant MFCN interference mechanism is blocking (i.e. high MFCN interfering signals driving WLAN devices into saturation). The level of blocking signal power does not change significantly with the frequency offset between the MFCN and WLAN channels.

The studies also showed that the number of affected devices is expected to be low and, in many cases, potential coexistence issues could be handled by careful siting of the equipment. After extensive engagement with mobile and WLAN industry, Ofcom noted that manufacturers were aware of the potential degradation in WLAN devices due to adjacent band interference and new devices were manufactured in light of this awareness and new WLAN devices were also equipped with dual band capability (i.e. 2.4 GHz and 5 GHz). Ofcom therefore decided that market developments (e.g. dual band capability and in-device filtering) were already underway and no intervention in the market was necessary in addition to adopting the limits defined in ECC Decision (14)02.

The specific measures included in ECC Decision (14)02 for the protection of WLAN devices coupled with the outcome of extensive studies performed in the UK suggest that adjacent band coexistence between MFCN and WLANs is feasible.

4 Recommendations

4.1 Sharing between MFCN and RurTel

The assumptions made in this report (Appendix A) are based on the operation of 35 RurTel link licences, which equates to 47 active point-to-multipoint links. The analysis in this report identified potential for co-channel interference over large geographic areas around the locations of the RurTel base station receivers.

Therefore, for MFCNs to be deployed in areas surrounding RurTel base station receivers, we would recommend that ComReg define a coordination procedure to ensure co-existence between proposed MFCN deployments and existing RurTel networks. The size of coordination areas varies with the assumed interference threshold as shown in Figure 2.1.

However, noting that co-channel interference impacts the deployment of MFCN over large geographic areas, Plum understands that ComReg, as part of its proposed award process, is considering the future of Eir's RurTel network in the 2.3 GHz band. In the event that the RurTel network is reduced or retired from the 2.3 GHz band, the requirement for a coordination procedure should be assessed to reflect any changes.

In the case of adjacent channel co-existence, the results show that adjacent channel coexistence between MFCN and RurTel is likely to be feasible in practice without any coordination requirements for most deployment scenarios. However, coordination could be required for the worst-case scenarios where the RurTel wanted power is at a minimum level, as depicted in Figure 2.4 and Figure 2.5.

While noting that uncertainty exists regarding the RurTel receiver performance (e.g. receiver selectivity) and link budgets, it is our view that adjacent channel coexistence between MFCN and Rurtel networks could be feasible without the implementation of coordination areas for most deployment scenarios.

4.2 Sharing between MFCN and WLANs

ECC Decision (14)02 specifies harmonised technical conditions in the form of BEMs to facilitate coexistence between MFCN base stations deployed in the 2.3 GHz band and systems (i.e. WLANs) operating above 2.4 GHz. These include implementing:

- a reduced in-block EIRP limit for the band 2390 – 2400 MHz, and
- additional baseline BEM out-of-band EIRP limits.

In addition to ECC Decision (14)02, the UK regulator (Ofcom) conducted a number of extensive studies on the coexistence of WLAN and MFCN base stations. The studies concluded, among other things, that the number of affected devices is expected to be low and, in many cases, potential coexistence issues could be mitigated by moving the WLAN device to an area less susceptible to MFCN interference. In addition, Ofcom noted that new WLAN devices are equipped with dual-band capabilities which use both 2.4 GHz and 5 GHz as well as in-device filtering to avoid harmful interference.

Taking into account the outcome of extensive studies performed in the UK, it is our view that in implementing the specific limits outlined in ECC Decision (14)02 for the protection of WLAN devices, adjacent band coexistence between MFCN and WLANs is feasible without additional implementation measures from ComReg.

Appendix A MFCN and RurTel system parameters

A.1 MFCN parameters

ECC Decision (14)02 defines 'Harmonised technical and regulatory conditions for the use of the band 2300 – 2400 MHz for Mobile/Fixed Communications Networks (MFCN)'. The Decision includes the least restrictive technical conditions in the form of BEMs to allow co-existence between MFCN applications in the band. BEMs are also intended to ensure coexistence with systems above 2400 MHz.

The Decision states that BEMs do not take account of coexistence with other incumbent services within the band. In addition to BEMs, further requirements may be needed in such instances which can be implemented at a national level.

In the context of the protection of incumbent RurTel service operating in the 2.3 GHz band, the key scenario that is likely to result in most stringent sharing requirements is the co-channel interference from wide area MFCN BS transmitters into RurTel BS receivers.

The Decision defines a non-obligatory EIRP limit of 68 dBm/5MHz for MFCN BSs operating in 2300 – 2390 MHz and 45 dBm/5MHz for MFCN BSs operating in 2390 – 2400 MHz. Furthermore, an EIRP limit of 25 dBm/5MHz is defined for the user equipment.

It should be noted that the Decision refers to ECC Report 172 (published in 2012) which provides compatibility studies between broadband wireless systems and other services operating in the 2.3 GHz band and adjacent bands. In the report, the broadband wireless system characteristics are based on LTE TDD and mobile WiMAX. The LTE system parameters refer to 3GPP base station and user terminal specifications. It is also noted that the assumed EIRP for the wide area BS transmitter is 60 dBm for the 5, 10 and 20 MHz channels. For the LTE user terminal, the EIRP is assumed to be 23 dBm for the 5, 10 and 20 MHz channels.

A.2 RurTel system parameters

Point-to-multipoint radio links are provided by RurTel in the bands 2307 – 2327 paired with 2407 – 2427 MHz. This service is operated by Eir to provide wireless telephony services to rural areas in the west of Ireland.

Most of the modelling parameters given in this section have been supplied by ComReg. There are 35 RurTel licences currently operational (which equates to 47[23] operational point-to-multipoint links), in the data provided to Plum by ComReg as shown in Appendix C. This data has been used in the modelling to take account of those receivers operating in the band 2307 - 2327 MHz.

The following table provides the RurTel BS receiver parameters assumed for each site.

Table A.1: RurTel BS Receive Parameters

Parameter	Assumed Value
RurTel Uplink Band	2307 – 2327 MHz
Channel Bandwidth (MHz)	2

[23] Since Rurtel is a point-to-multipoint system, its licence can include more than one link.

Parameter		Assumed Value
Antenna	Type	Omni
	Gain (dBi)	10
	Feeder Loss (dB)	2
Receiver Noise Figure (dB)		3
Receiver Noise Floor (dBm)		-108
Wanted Carrier Level (dBm)	Minimum	-94.5
	Nominal	-62
	Maximum	-45
Assumed C/(N+I) Threshold (dB)		10
Assumed Interference Threshold (dBm)	Minimum	-107
	Nominal	-72
	Maximum	-55

A.3 Parameters assumed for modelling

The modelling assumptions are shown in the following table.

Table A.2: Modelling Assumptions

Parameter		Assumptions	Comments
		RurTel BS Receiver	Data provided by ComReg via eircom.
Channel Bandwidth (MHz)		2	
Omnidirectional Antenna	Type	Omni	Omnidirectional antenna is assumed to represent the worst case in terms of calculated coordination areas.
	Gain (dBi)	10	
	Feeder Loss (dB)	2	
Receiver Noise Figure (dB)		3	
Receiver Noise Floor, N (dBm)		-108	
Received Signal Strength, C (dBm)		-94.5 (Min) -62 (Nominal) -45 (Max)	

Parameter	Assumptions	Comments
C/(N+I) Threshold (dB)	10	Literature review[24] suggests that RurTel equipment was supplied by ALCATEL in 1990's. The equipment uses TDM / TDMA technique to support 28 time-slots allocated to 64 kbps voice channels and 3 time-slots sub-multiplexed to support 18 data channels of 2.4 kbps and one slot for the network control. It is assumed that the system uses BPSK or QPSK modulation with BERs in the range 10^{-3} or 10^{-6}.
Interference Threshold (dBm)	-107 (Min) -72 (Nominal) -55 (Max)	Based on the minimum, nominal and maximum received power levels and an assumed C/(N+I) threshold.
	MFCN BS Transmitter	
Maximum EIRP (dBm/10MHz)	71	Based on ECC Decision (14)02[25]
Antenna Gain (dBi)	18	
	Propagation	
Path Loss Model	ITU-R Rec.452	
Percentage Time	0.1%	
Terrain Model	SRTM	

[24] https://camiguintelekom.wordpress.com/2008/02/23/are-the-days-of-small-telcos-numbered/ and https://www.itu.int/bibar/ITUJournal/DocLibrary/ITU011-1993-12-en.pdf

[25] There is also on-going work, for example within CEPT, regarding the emission limits for base stations to be deployed with Active Antenna Systems. These limits are described in the form of total radiated power at the active antenna input. In this study, it is assumed that operating conditions of these systems would not, overall, result in more stringent co-existence requirements.

Appendix B Large scale interference maps

B.1 Co-channel interference

Figure B.1: Donegal

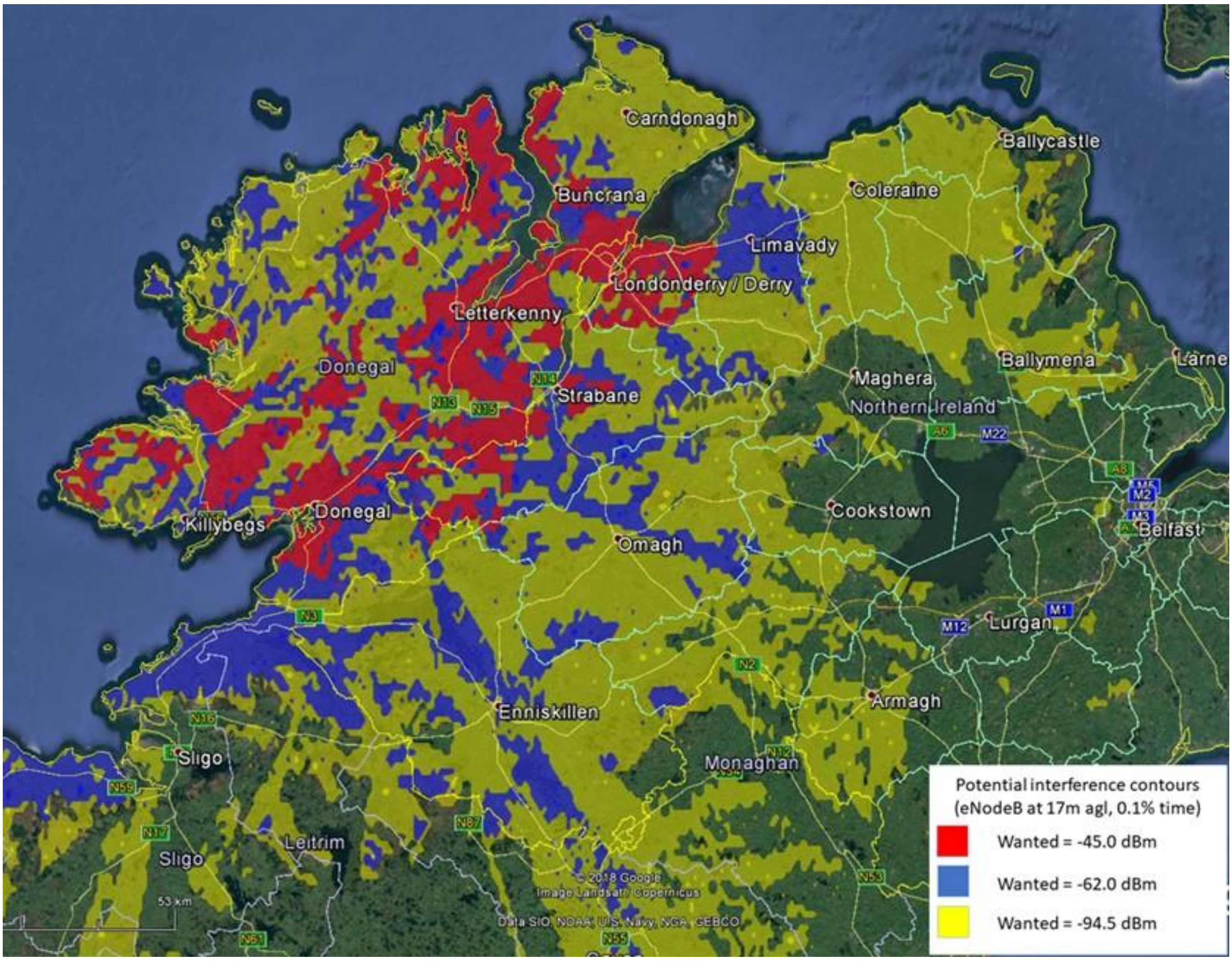


Figure B.2: Galway

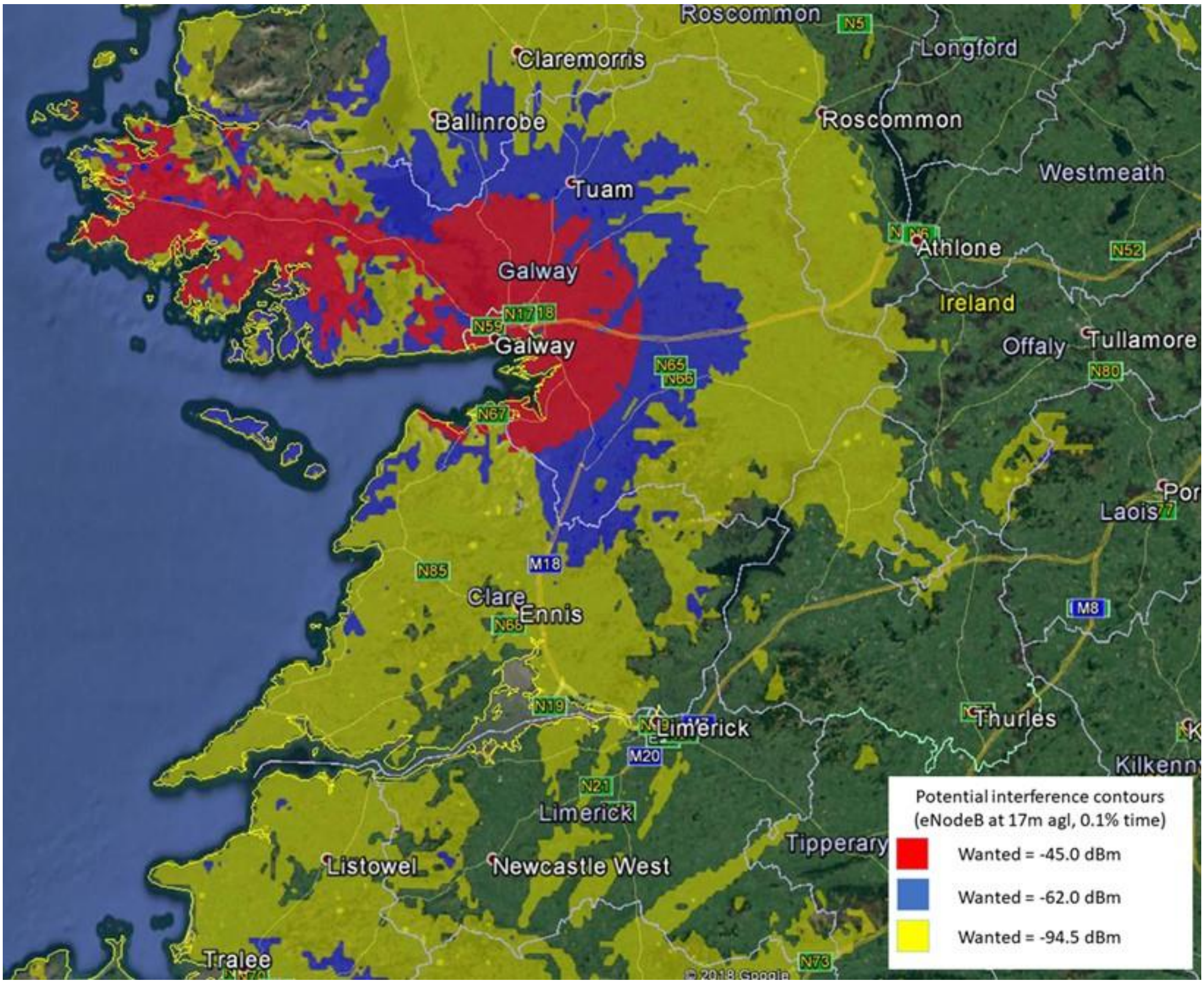
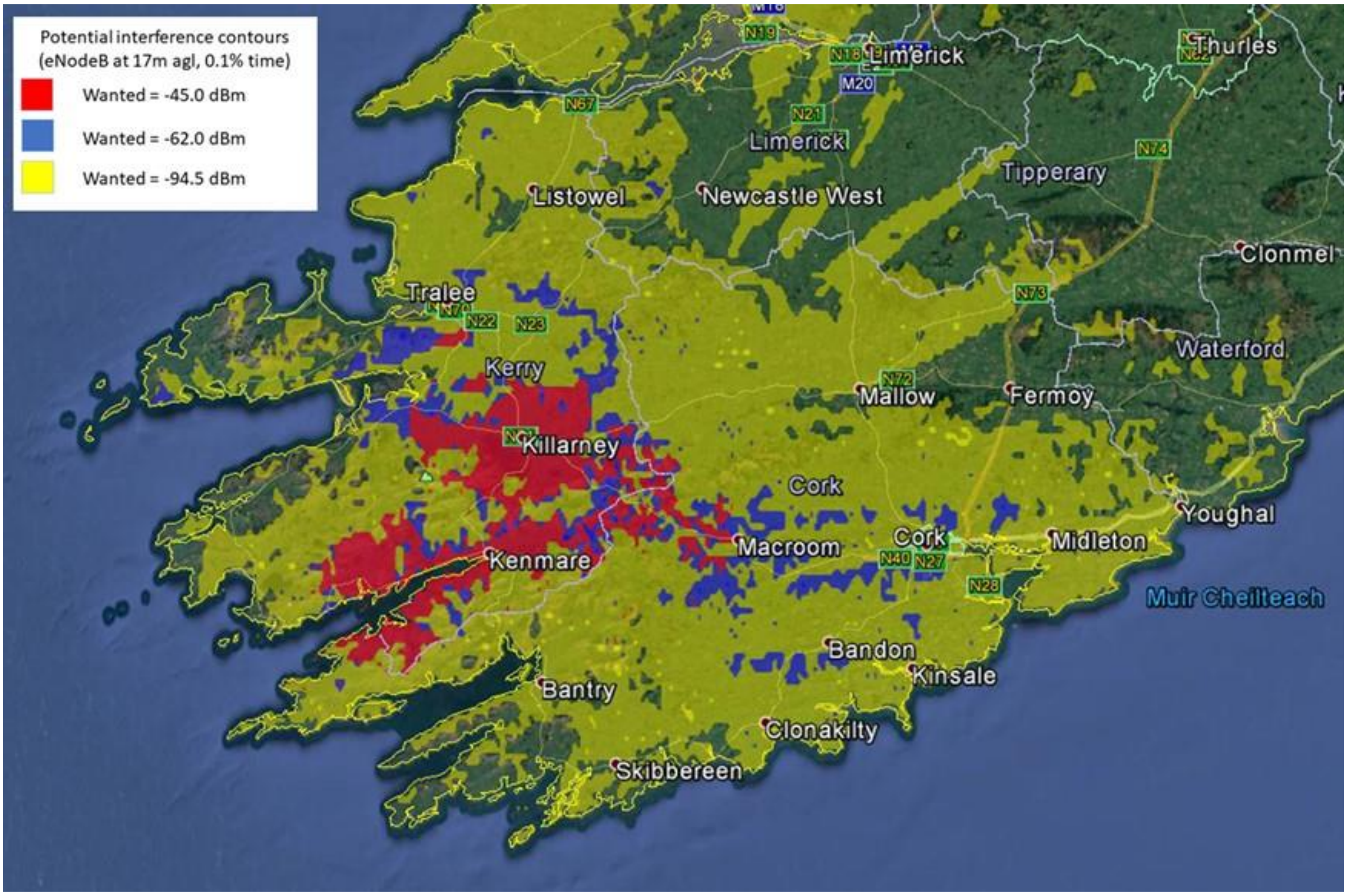


Figure B.3: Kerry



B.2 Adjacent-channel interference (50 dB rejection)

Figure B.4: Donegal

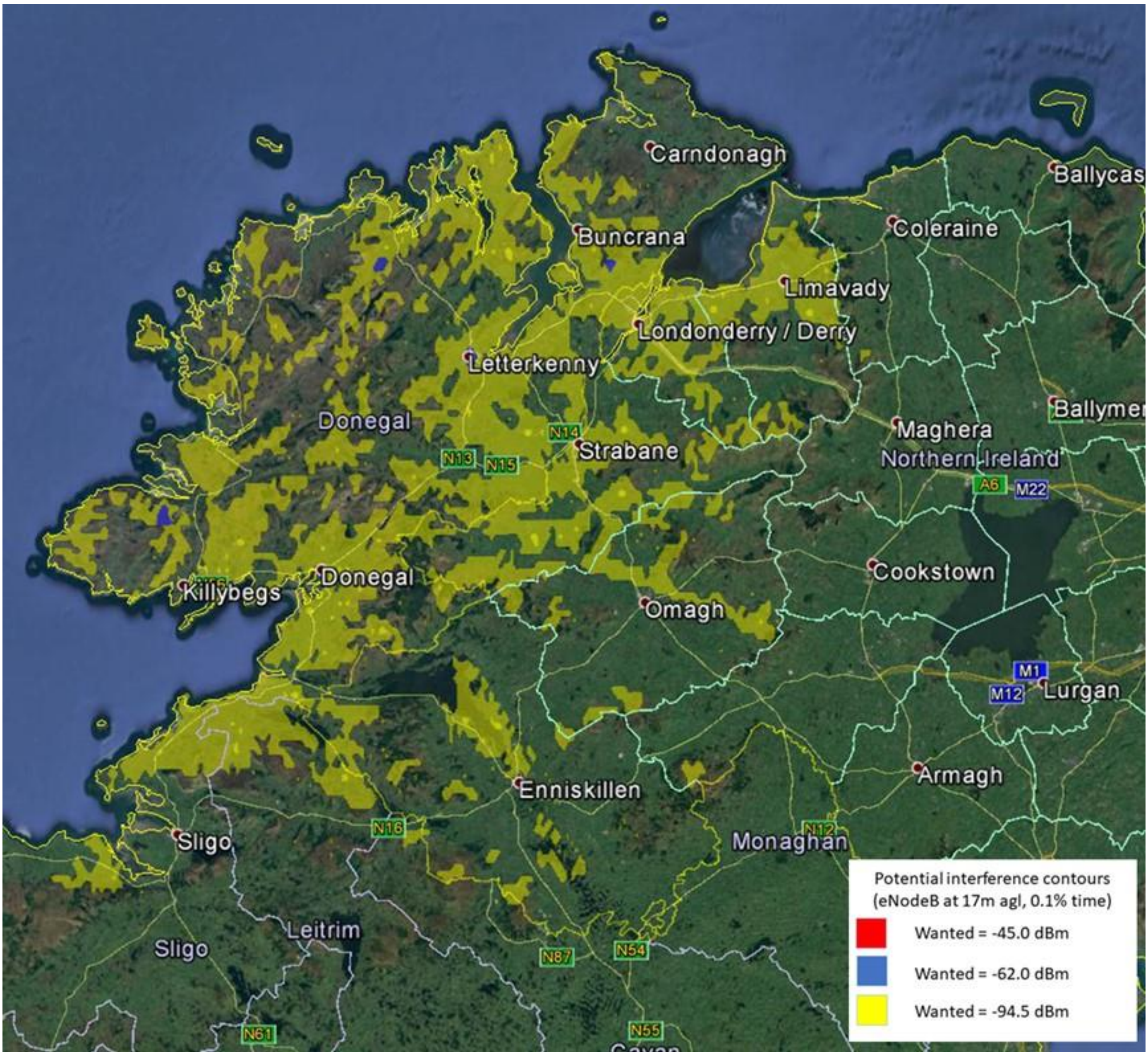


Figure B.5: Galway

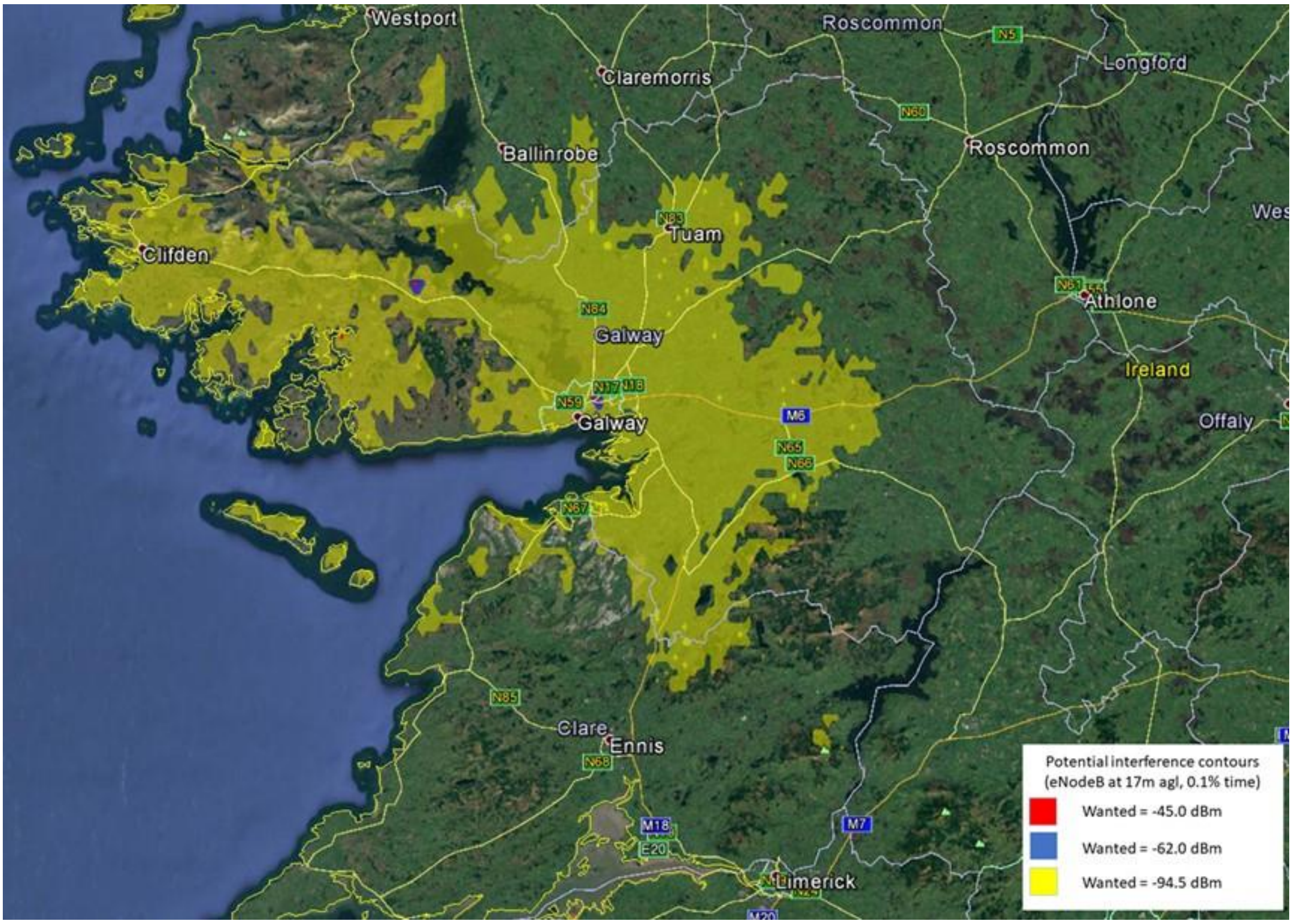
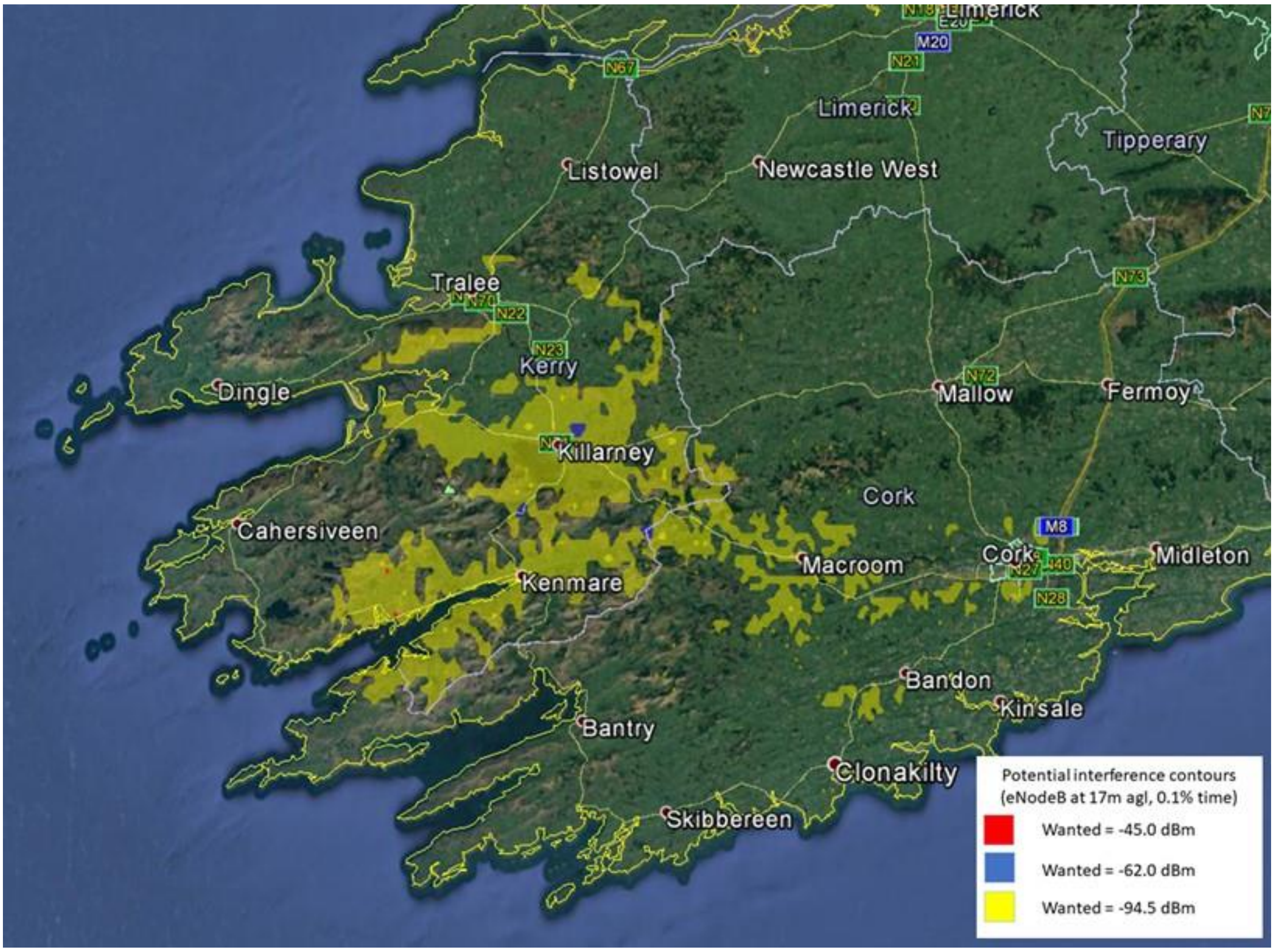


Figure B.6: Kerry



B.3 Adjacent-channel interference (40 dB rejection)

Figure B.7: Donegal

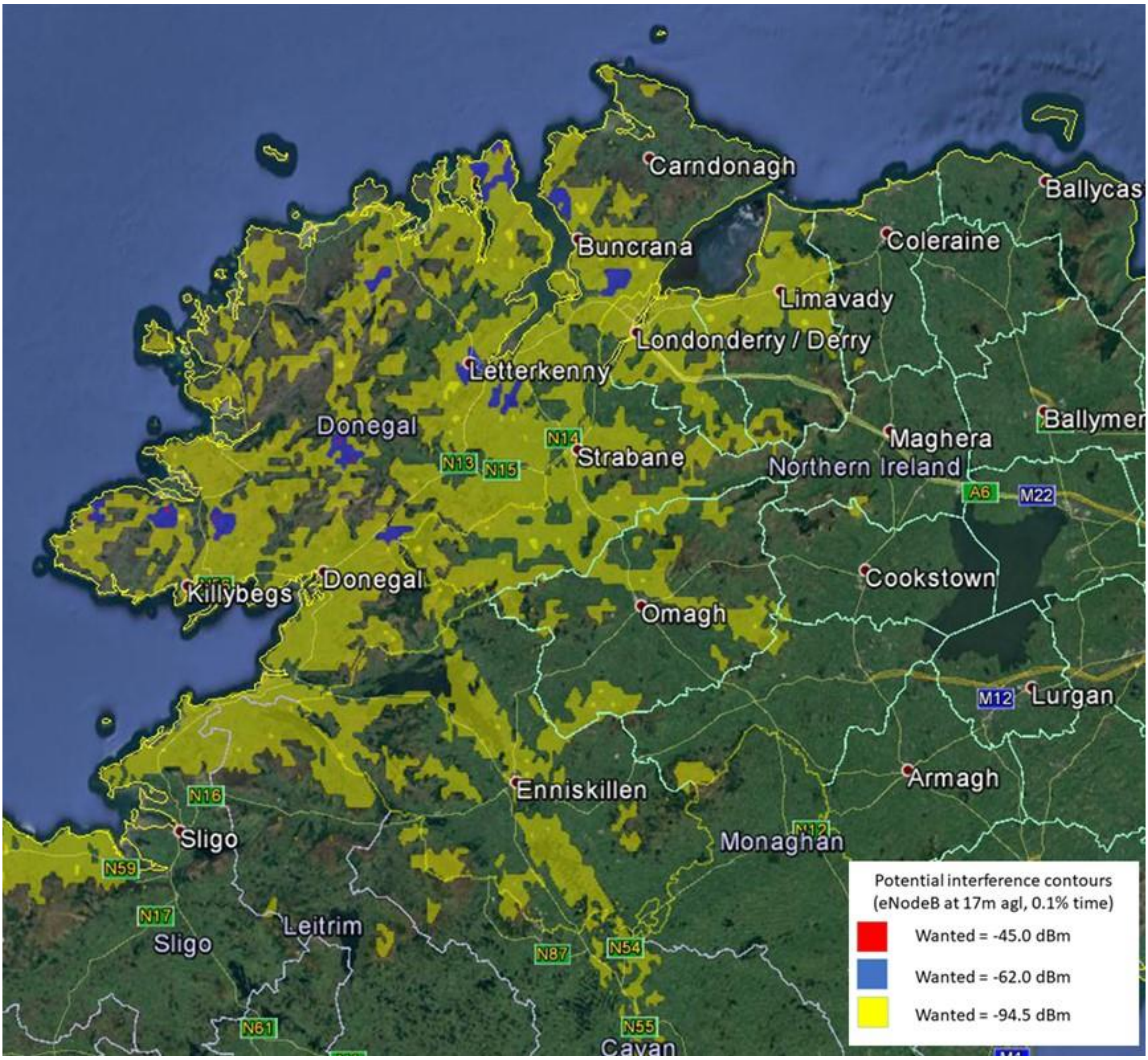


Figure B.8: Galway

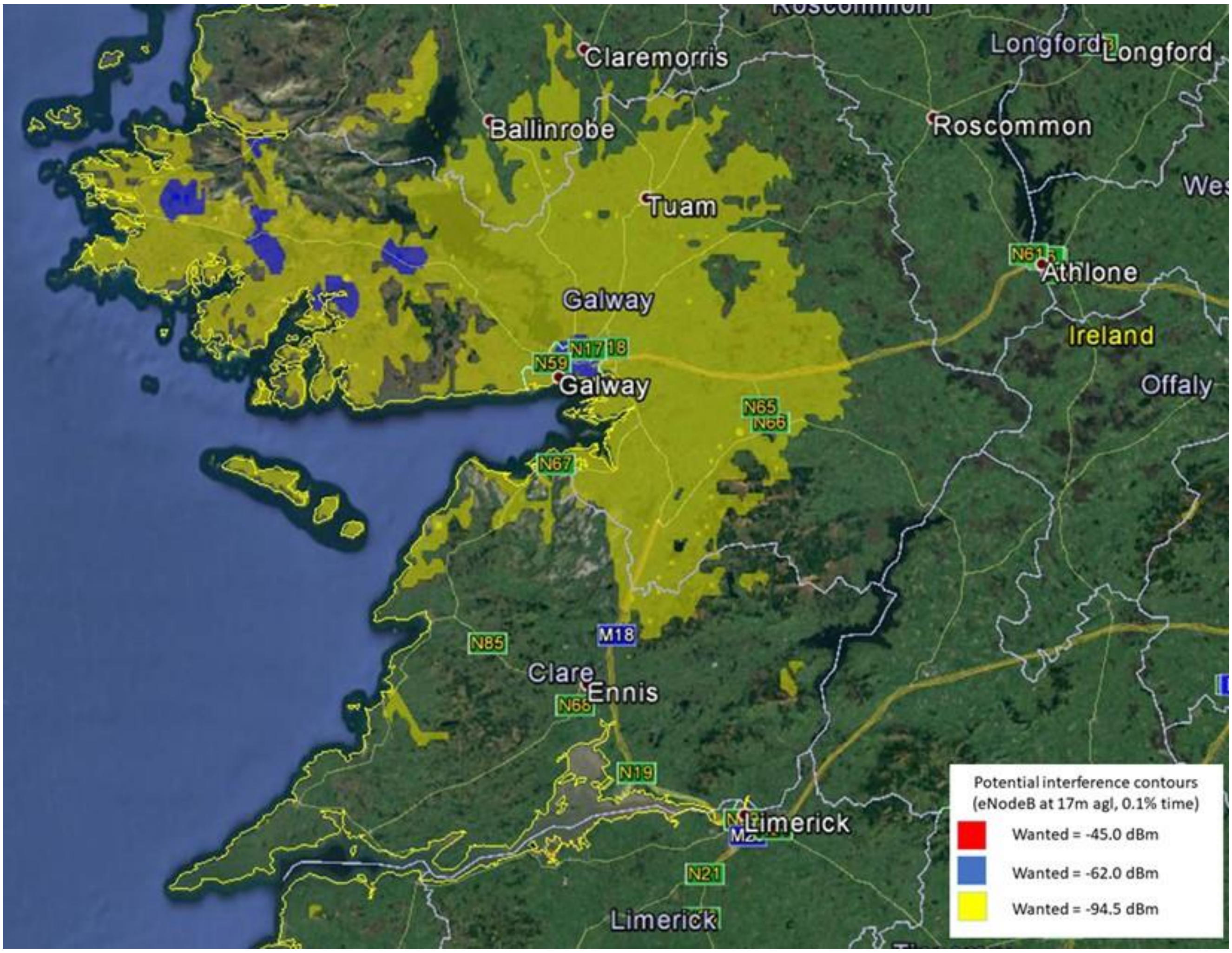
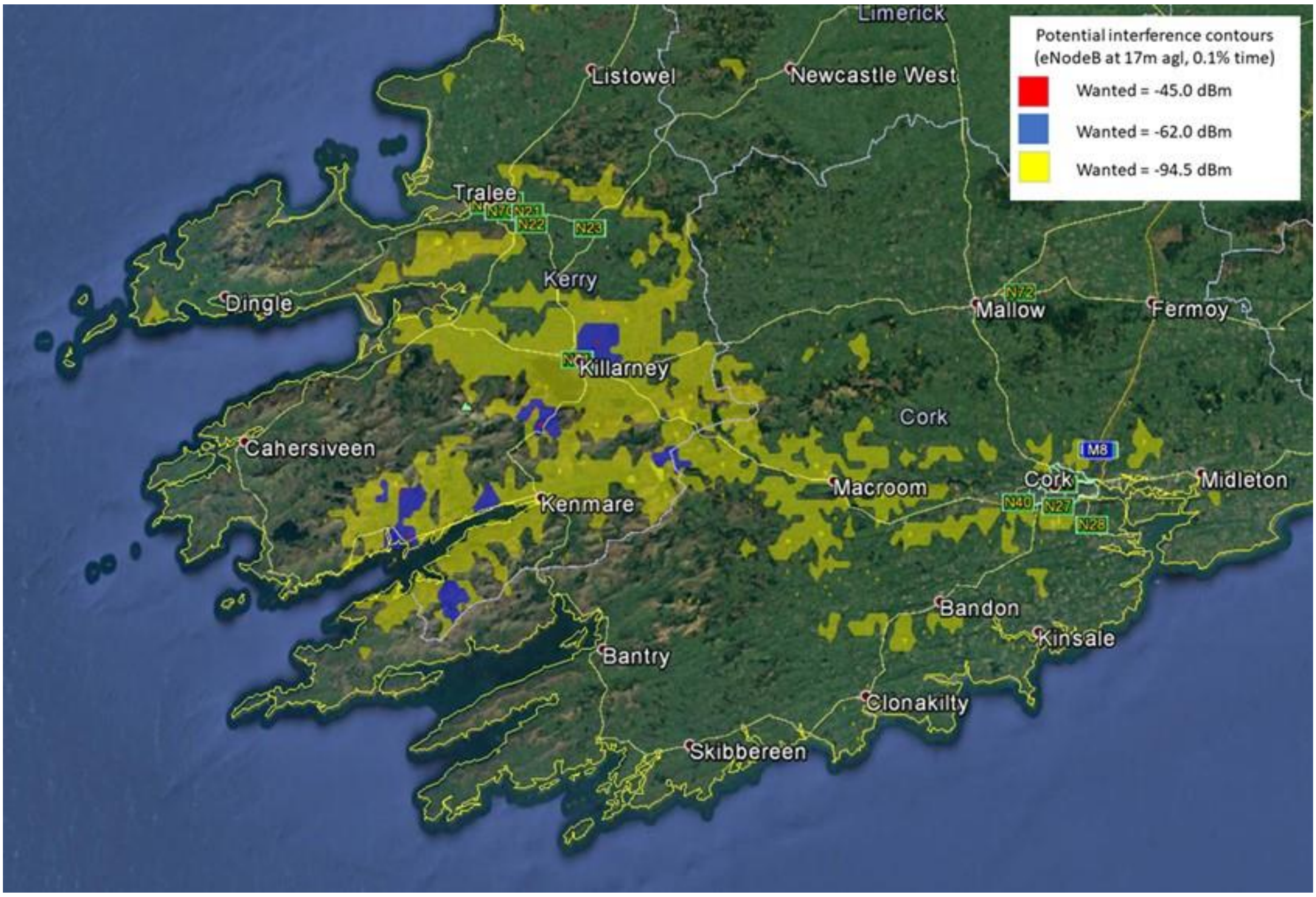


Figure B.9: Kerry



Appendix C RurTel Point to Multipoint Data

	Site Name	Latitude (DD MM SS)	Longitude (DD MM SS)	Site Name	Latitude (DD MM SS)	Longitude (DD MM SS)
1	Bunnaton DK	55N1042	07W3139	Asdevlin DK	55N0450	07W2305
2	Bunowen DK	53N3535	09W4727	Lehanagh DK	53N2943	09W4332
3	Camus DK	53N2215	09W3443	Feaghroe DK	53N2547	09W4516
4	Capparoe DK	51N5148	09W4334	Clogherane	51N4420	09W4512
5	Capparoe DK	51N5148	09W4334	Derryquinn	51N4918	09W5216
6	Capparoe DK	51N5148	09W4334	Inchee DK	51N5623	09W1820
7	Carrickagh DK	54N4852	08W0039	Toneyancil Hill DK	54N4852	08W0231
8	Chara DK	55N1330	07W2933	Bunnaton DK	55N1045	07W3135
9	Creaslough DK	55N0414	07W5847	Glassan DK	55N0515	07W5730
10	Asdevlin DK	55N0447	07W2310	Bunnaton DK	55N1045	07W3135
11	Asdevlin DK	55N0447	07W2310	Letterkenny DK	54N5701	07W4402
12	Eifernagh DK	54N4718	08W0327	Carrickagh DK	54N4908	08W0034
13	Eskine DK	51N5323	09W4944	Capparoe DK	51N5150	09W4330
14	Eskine DK	51N5323	09W4944	Tullakeel	51N5241	09W5325
15	Evisbreedy DK	55N0931	07W1927	Asdevlin DK	55N0450	07W2305
16	Feaghroe DK	53N2547	09W4516	Ballinahinch DK	53N2827	09W4828
17	Fintown DK	54N5739	08W0526	Maghera DK	52N5800	08W4300
18	Ballinahinch DK	53N2827	09W4828	Creggs DK	53N3021	09W5619
19	Ballinahinch DK	53N2827	09W4828	Knockletterfore DK	53N2621	09W2500
20	Inchee DK	51N5623	09W1820	Capparoe DK	51N5150	09W4330
21	Inchee DK	51N5623	09W1820	Knockaninane DK	52N0512	09W2524
22	Killarney DK	52N0432	09W2757	Inchee DK	51N5623	09W1820
23	Knockaninane DK	52N0512	09W2524	Inchee DK	51N5623	09W1820
24	Knockaninane DK	52N0512	09W2524	Lady's view DK	51N5756	09W3544
25	Knockletterfore DK	53N2619	09W2504	Camus DK	53N2215	09W3443
26	Knockletterfore DK	53N2619	09W2504	Mervue DK	53N1720	09W0106
27	Lady's view DK	51N5756	09W3544	Derrynahierka	51N5809	09W3537
28	Lady's view DK	51N5756	09W3544	Killarney DK	52N0432	09W2757
29	Leamagowra DK	54N4325	08W3022	Maghera DK	52N5800	08W4300

	Site Name	Latitude (DD MM SS)	Longitude (DD MM SS)	Site Name	Latitude (DD MM SS)	Longitude (DD MM SS)
30	Leamagowra DK	54N4325	08W3022	Maum DK	54N4435	08W3100
31	Lehanagh DK	53N2943	09W4332	Bunowen DK	53N3535	53N3535
32	Lehanagh DK	53N2943	09W4332	Feaghroe DK	53N2547	09W4516
33	Lettercallow DK	53N1727	09W3960	Camus DK	53N2215	09W3443
34	Ballyhark North DK	55N1257	07W4327	Ballinahinch DK	55N1538	07W3916
35	Loughmuilt DK	54N4009	08W2203	Mulmosog DK	54N4355	08W2330
36	Maum DK	54N4433	08W3102	Leamagowra DK	54N4325	08W3022
37	Mervue DK	53N1720	09W0106	Knockletterfore DK	53N2619	09W2504
38	Mongorry Hill DK	54N5325	07W3801	Letterkenny DK	54N5701	07W4402
39	Mulmosog DK	54N4352	08W2340	Barnesmore DK	54N4258	07W5633
40	Murren Hill DK	55N1339	07W3943	Boulty Patrick DK	54N5010	08W0412
41	Ballysaggart DK	54N3528	08W2512	Mulmosog DK	54N4345	08W2340
42	Toneyancil Hill DK	54N4852	08W0231	Barnesmore DK	54N4258	07W5633
43	Toneyancil Hill DK	54N4852	08W0231	Carricagh DK	54N4855	08W0039
44	Tullybeg DK	54N4805	08W2240	Maghera DK	52N5800	08W4300
45	Barnesmore DK	54N4256	07W5633	Mongorry Hill DK	54N5327	07W3801
46	Boulty Patrick DK	54N5010	08W0412	Mulmosog DK	54N4355	08W2330
47	Boulty Patrick DK	54N5010	08W0412	Murren Hill DK	55N1339	07W3943