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Spectrum award – 3.6 GHz band.

Technical advice from Plum Consulting concerning potential rights of use in the 3.6 GHz band.

Report 1: Co-existence recommendations

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Technical advice concerning potential rights of use in the 3.6 GHz band.

Report 1: Co-existence recommendations

Technical Analysis

A report for ComReg

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Executive Summary

Introduction

This study is intended to inform the technical requirements for co-channel co-existence between Mobile/Fixed Communications Networks (MFCN) using the same frequency blocks in neighbouring areas (regional or into the UK) in the 3.6 GHz band (3400 – 3800 MHz).

Approach

The co-existence analysis methodology adopted in this study includes three steps:

- Establish a suitable metric for the licensing of networks,
- Derive potential coordination threshold levels for the metric chosen to accommodate various deployment scenarios involving networks of macro, micro, pico and femto base stations,
- Demonstrate the impact of coordination threshold levels using example interference scenarios and by considering potential mitigation measures.

Although the preferred duplexing scheme is TDD there is also the potential for FDD deployment in the lower part of the band between 3400 – 3600 MHz. We understand ComReg is likely to allow the existing Fixed Wireless Access Local Area (FWALA) licensees to compete to acquire new rights of use in the proposed award process and, if successful, continue their service provided they can meet the necessary technical and other licence conditions. The deployment of such diverse networks can lead to interference paths between base stations and user terminals.

Considering a wide range of deployments scenarios (including MFCN / FWALA, synchronised TDD / unsynchronised TDD / FDD, macro / micro / pico / femto base station networks and urban / rural environments) and victim link fade margins (including 1, 3 and 7 dB), the following generic metric and associated threshold levels have been assumed to protect base station and user terminal receivers at the regional border between different operators.

- ***Base station receivers:*** field strength thresholds in the range 30 – 60 dBµV/m/5MHz to be satisfied for 90% of time and 90% locations at 10 m height
- ***User terminal receivers:*** field strength thresholds in the range 30 – 65 dBµV/m/5MHz to be satisfied for 90% of time and 90% locations at 3 m height

Using these thresholds, impact assessment has been undertaken for interference paths between base stations, base stations and user terminals and user terminals. Example sites in Ireland have been selected to undertake simulation modelling by incorporating Irish terrain data based on Shuttle Radar Topography Mission (SRTM) database into ITU-R Rec.452 model. The aim of the modelling is to show the impact of assumed thresholds by deriving representative interference areas centred on a typical interfering base station / user terminal transmitter.

Outcome

When ***unsynchronised TDD networks*** are deployed on either side of a regional border detrimental base station to base station, base station to user terminal, user terminal to base station and user terminal to user terminal co-channel interference paths can occur. In such deployment scenarios, coordination threshold requirements are mainly determined by base station to base station interference as the height and EIRP of base stations are higher than those of user terminals.

The analysis of base station to base station interference paths using example sites indicate that a typical macro base station urban deployment scenario gives rise to an interference area limited to approximately 30 km from the transmitter location for the most stringent criterion (i.e. 30 dBμV/m). This is reduced to 15 km for micro base station transmitter and 10 km for pico base station transmitter. In a typical rural scenario where a macro base station is placed at a hilltop, the area of interference can extend up to 60 km from the transmitter location.

A number of mitigation measures can be deployed to ease these requirements and would be considered as part of detailed network planning. Achievable benefits are very much scenario dependent but are likely to result in being able to deploy base stations closer to the regional boundary or limit the potential for interference into user terminals in the adjacent regional area. Potential mitigation measures for base station to base station interference include the following.

- Antenna shielding to increase the interference path loss (for example, 20 dB shielding can reduce the interference area from 33 km to 13 km in urban macro base station deployment scenario),
- Antenna pointing away from the regional borders (for example, the urban macro base station distance is reduced from 33 km in the antenna main beam direction and 12 km in the antenna back lobe direction; similarly, in cross border scenarios, calculated distances from the border are approximately 10 km when antennas point away from the border),
- Antenna height reduction to increase the interference path propagation loss (for example, a third reduction in calculated separation distance in certain directions is achieved when the antenna height is reduced from 30 m to 10 m),
- Transmitter power reduction to decrease the interference power (for example, when a macro base station EIRP is reduced from 60 dBm/5MHz to 40 dBm/5MHz the limit of the interference area in most directions reduces from 33 km to 13 km),
- Antenna downtilting to enable additional antenna discrimination on the interference path (for example, an additional discrimination of approximately 5 dB is obtained when a macro base station antenna is downtilted by 6 degrees),
- The use of directional / smart antennas to reduce the spillage over neighbouring areas,
- Heterogeneous networks deploying micro / pico base stations near the regional borders,
- Antenna polarisation in fixed deployment scenarios,
- Synchronising networks on either side of the regional border to eliminate base station to base station interference paths,
- The use of preferential channels on either side of the regional border to eliminate co-channel interference scenarios.

When ***synchronised TDD and/or FDD networks*** are deployed on either side of a regional border base station to base station and user terminal to user terminal interference paths do not arise. In such deployment scenarios, coordination threshold conditions are driven by interference paths between base stations and user terminals.

The analysis of base station to user terminal and user terminal to base station interference paths using example sites indicate that the coordination threshold requirements for macro base station to user terminal interference are more stringent than those calculated for user terminal to base station interference. For example, in a typical urban deployment scenario, the area of interference extends to approximately 30 km from a macro base station transmitter and 15 km from a user terminal transmitter for the most stringent criterion (i.e. 30 dBµV/m). Similarly, in a typical rural deployment scenario, the interference area extends up to approximately 50 km from an elevated base station transmitter and 30 km from a user terminal transmitter.

Mitigation measures identified for the unsynchronised TDD deployments can also apply to synchronised TDD and FDD deployments. One of the key factors is the additional clutter loss that might be applicable in many scenarios involving user terminal receivers. For example, an additional 20 dB clutter loss can reduce the limit of interference area from 32 km to approximately 10 km in most directions for an urban macro base station transmitter. Furthermore, the user terminal transmit power control might be beneficial in scenarios where the user terminal is located near the regional border.

Cross border analysis into UK

The objective of the ***cross border interference analysis*** is to examine the impact of field strength thresholds specified in the current MoU between Ireland and the UK and ECC Recommendation (15) 01. Analysis with terrain, using example sites near Northern Ireland, has shown that thresholds are most likely to be exceeded over a limited area near the border, e.g. within 10 km. The noticeable exception, is hilly areas, which can extend the areas affected to 20 – 25 km from the border but it is likely that many of these are not populated.

Recommendations

We would propose that a ***co-channel coordination threshold level of 32 dBuV/m/5 MHz for 90% of the time and 90% of the locations at regional borders*** is adopted. This is to be in line with:

- typical receiver equipment characteristics that might be deployed in the band,
- an assumed conservative protection level of "6 *dB below the victim receiver noise floor"* (which is used in ECC Report 203 and implies 1 dB loss in victim link fade margin due to interference),
- percentage of time and location assumptions adopted for cross-border agreements,
- calculated required separation distances to the regional border in example scenarios analysed in this study, and
- the stringent cross-border threshold level specified in ECC Recommendation (15)01.

The height associated with this level can be 10 m when networks on either side of the border are unsynchronised (i.e. the dominant interference path is into a base station receiver) and 3 m when they are synchronised (i.e. the dominant interference path is into a user terminal receiver).

It is worth noting that if a more relaxed criterion is chosen the overall area affected by interference is reduced in some of the example cases but there are typically still a few directions where the relaxed criterion does not have a significant impact.

It is also worth noting that the operators can negotiate a less stringent criterion among themselves.

1 Introduction

The information provided in this report is intended to inform the technical considerations, for the future licensing and use of the 3.6 GHz band (3400 – 3800 MHz) in Ireland, following the expiry of the existing rights of use for Fixed Wireless Access Local Area (FWALA) licences in 2017.

In this report, a suitable metric has been identified to facilitate co-channel co-existence among Mobile/Fixed Communication Networks (MFCN) including IMT. For the identified metric, the implications of a set of threshold levels representing various deployment scenarios (e.g. macro, micro, pico and femto) have been examined. The implications of co-existence with systems currently occupying the band and cross border interference into the UK have also been investigated.

1.1 Co-existence of 3.6 GHz Services

Co-existence conditions are defined to optimise spectrum usage and avoid loss of network capacity by limiting interference between adjoining networks. Two co-existence scenarios must be considered – *adjacent channel* where two networks may be operating in adjacent frequencies, in the same geographic area and *co-channel* where two networks may be operating on the same frequency, in adjacent geographic areas.

Adjacent frequency co-existence requirements among MFCN have already been studied and addressed within the CEPT. The key CEPT document in this regard is ECC Report 203 where adjacent frequency requirements are expressed as Block Edge Masks (BEMs) specifying maximum allowed Equivalent Isotropic Radiated Power (EIRP), as a function of frequency offset from the edge of a frequency block assigned to an operator. In ECC report 203, different BEMs are defined for TDD and FDD base stations based on an assumed minimum geographic separation between 10 – 70 m between interfering and victim macro/micro/pico/femto base stations. The CEPT work also concluded that the adjacent band sharing between MFCN systems and other services (e.g. fixed links and satellite systems) needs to be assessed on a case-by-case basis. The outcome of the CEPT work on the adjacent band sharing is incorporated into ECC Decision (11)06 (March 2014) and EC Decision 2014/276/EU (May 2014)[1].

The primary objective of the analysis provided in this study is to outline co-channel sharing requirements and recommendations for the new licensing regime to be adopted in Ireland taking into account Irish specific scenarios. The CEPT band plan indicates that the preferred duplexing scheme for the band is TDD although it allows for the adoption of a FDD channelling arrangement for the lower part of the band (i.e. 3400 – 3600 MHz). Therefore, there is the potential that under the new regime, a mix of FDD, synchronised TDD and unsynchronised TDD MFCN might be deployed using macro/micro/pico/femto base stations. We understand ComReg is likely to allow the existing 3.6 GHz FWALA operators to compete to acquire new rights of use in the proposed award process and, if successful, continue their service provided they can meet the necessary technical and other licence

[1] ComReg will need to define the applicable adjacent channel criterion for networks operating in the same geographic area based on the requirements of the EC 2014 Decision and the proposed mode of operation (FDD or TDD in the 3400 – 3600 MHz band). This will require the Block Edge Masks to be defined depending on whether it is decided to require non-synchronised or synchronised co-existence between networks. The Block Edge Masks will define the in-block and out-of-block power limits as well as the transitional levels between the lower and upper block edges for different frequency separations. See Section 2.2 for further information.

conditions. The deployment of such diverse networks can lead to interference paths between base stations and user terminals.

1.2 Overview of Methodology

The methodology adopted in this study to examine co-existence requirements includes three steps:

- Establish a suitable metric for the licensing of MFCN,
- Derive potential coordination threshold levels for the metric chosen to accommodate various deployment scenarios involving networks of macro, micro, pico and femto base stations,
- Demonstrate the impact of coordination threshold levels using example interference scenarios and by considering potential mitigation measures

In establishing a suitable metric to assess the feasibility of co-existence between networks deployed in adjacent regions, it is proposed to adopt field strength thresholds which is the approach adopted for cross border coordination to facilitate sharing along the border. A field strength level, defined at a representative height at the regional border to be satisfied at a given percentage of time and location, is therefore chosen as a suitable metric for assessing coordination threshold requirements.

In order to derive appropriate field strength threshold levels, receiver characteristics need to be examined. Using the representative macro/micro/pico/femto network receiver parameters assumed in ECC Report 203 and the data provided by ComReg on the existing FWALA receiver parameters, a range is defined for the potential field strength threshold levels to cover different types of receiver.

The implications of adopting these field strength threshold levels have been examined by developing various interference scenarios. Areas where threshold field strength levels are exceeded have been calculated for example sites by taking account of terrain effects to inform deployment distances from a regional border. Potential mitigation measures have been identified. Pessimistic deployment distances have also been calculated without terrain and other mitigation measures.

In the remainder of this report, a critical review of existing CEPT and EC work is provided. A detailed description of the approach adopted in the analysis is presented. This is followed by the outline of system parameter values used in the analysis. Co-existence scenarios and corresponding analysis results are then presented. Potential mitigation measures are explained. In the final section, a summary of the analysis results is provided together with conclusions and recommendations.

2 Harmonisation of the 3.6 GHz band in Europe

2.1 Introduction

In the following sections, we summarise the 3400 – 3800 MHz frequency band studies (and associated documents) undertaken in Europe in response to EC mandates that have led to the development of technical requirements to "ensure technical compatibility between existing and new users of the band, efficient spectrum use and avoidance of harmful interference[2]".

The aim is to identify the key technical requirements and issues applicable for any future rights of use in the 3.6 GHz band that need to be taken into consideration by ComReg.

2.1.1 EC Decision 2014/276/EU

European Commission Decision 2014/276/EU[3] which amended the previous EC Decision 2008/411/EC requires "that Member States shall apply the conditions laid down in the Annex on 30 June 2015 at the latest" for new rights of use for terrestrial electronic communications networks in the 3 400-3 800 MHz frequency.

Annex 1 of the EC Decision defines the general parameters that should be implemented, namely:

- TDD preferred mode of operation in 3400 – 3600 MHz sub-band but FDD may be implemented to ensure greater spectrum efficiency, protect existing users or avoid interference and for the purposes of co-ordination with non-EU countries;
- TDD mode of operation to be used in 3600 – 3800 MHz sub-band; and
- Block sizes to be multiples of 5 MHz with sub-band edges to be 3400 and 3600MHz for TDD and 3410 and 3510 MHz for FDD respectively.

The Annex also details the relevant block edge masks that should be used and these are described further in Section 2.2.

The technical conditions and channelling arrangements set out in 2014 EC Decision was developed as a consequence of work carried out in the CEPT as documented in the following publications.

CEPT Report 49

CEPT Report 49[4] is constructed as a response to EC Mandate[2] and presents the findings of the detailed analysis given in ECC Report 203 in the form of a proposed base station BEM as well as channel plans for sub-bands 3400 – 3600 MHz and 3600 – 3800 MHz.

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[2] EC Mandate "Technical conditions regarding spectrum harmonisation for terrestrial wireless systems in the 3400-3800 MHz frequency band", November 2013

[3] http://www.erodocdb.dk/Docs/doc98/official/pdf/2014276EU.PDF

[4] http://www.erodocdb.dk/Docs/doc98/official/pdf/CEPTREP049.PDF

ECC Decision (11)06

ECC Decision (11)06[5] which was amended in March 2014 to align it with the 2014 EC Decision, provides the technical parameters for harmonised frequency arrangements for MFCN operating in the 3.6 GHz bands.

ECC Report 203

The report[6] outlines the least restrictive technical conditions suitable for MFCN in the frequency bands 3400 – 3800 MHz by defining appropriate BEMs for the band. It is important to note, that the masks were developed to facilitate adjacent channel co-existence among different operators, using the band 3400 – 3800 MHz. Although additional limits are defined for the protection of military radiolocation below 3400 MHz the masks do not consider sharing with other services in adjacent bands (e.g. satellite and fixed links). ComReg may need to consider if there is a need to define different technical requirements for the upper edge of the block mask for the protection of any services operating immediately above 3800 MHz

However in respect of the 3400 to 3800 MHz band in Ireland the only sharing that needs to be considered is with State Services that currently operate in the 3435 – 3475 MHz band and the implications of these services remaining in the band have not been considered as part of this Study.

2.2 Block Edge Masks

2.2.1 Introduction

BEMs enable adjacent channel co-existence by limiting transmitter emissions at frequencies outside an operator's licensed blocks.

In the sections below we provide a summary of the BEM requirements as defined in EC Decision 2014/276/EU, CEPT Report 49, ECC Decision (11)06 and ECC Report 203 and a summary of the BEM calculation approach is provided in Appendix A to this report.

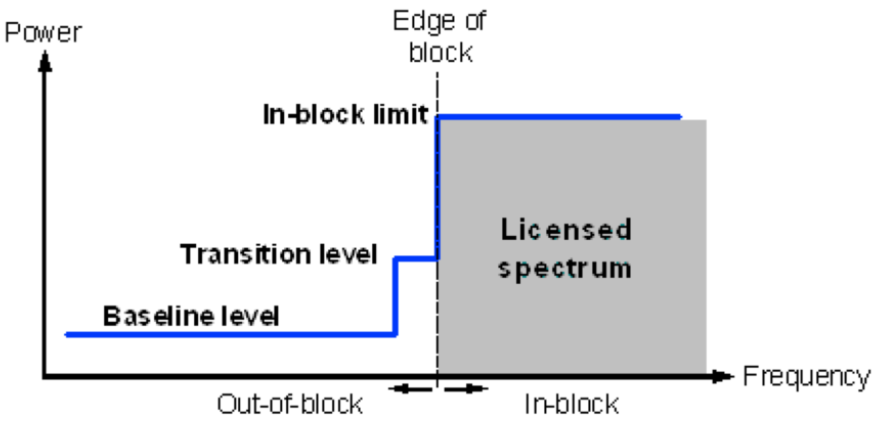
2.2.2 Base Station BEMs

The BEM elements that are defined in ECC Report 203 are illustrated below:

[5] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC1106.PDF

[6] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP203.PDF

Figure 2-1: Block Edge Mask Elements (Source: ECC Report 203)



A non-obligatory in-block EIRP limit is proposed as 68 dBm/5MHz per antenna which can be used if desired by an administration to limit the power used by the licensed operator. In practice, this level is likely to be an appropriate limit for the in-band emissions. For example, data provided by existing operators in Ireland indicates that there are no base station transmitters exceeding the 68 dBm/5MHz level. ComReg will need to decide whether they feel it is appropriate to limit the transmitter power of a base station.

The other base station limits are:

Table 2-1: Out-of-block baseline power limit

	Permissive mask (synchronised)	Restrictive mask (unsynchronised)
Band / mode	3400 – 3800 MHz TDD / 3510 – 3590 MHz FDD(down-link)	3400 – 3800 MHz TDD / 3410 – 3490 MHz FDD (up-link)
Out of block baseline power limit	Minimum of (In-block EIRP – 43) dBm / 5 MHz and 13 dBm / 5 MHz per antenna	-34 dBm / 5 MHz per cell

The baseline limits apply to all blocks except those in the transitional regions (see Table 2-2 below) and operators own blocks.

Transitional bands extend from the edge of the operator's own blocks to 10 MHz on either side of these blocks. The power limits are defined to enable a reduction for the in-block level to the baseline or guard band levels. Two EIRP limits are defined for the transitional bands as shown below:

Table 2-2: Transitional region power limits

Frequency range	-5 to 0 MHz offset from lower block edge 0 to 5 MHz offset from upper block edge	-10 to -5 MHz offset from lower block edge 5 to 10 MHz offset from upper block edge
Transitional region power limit	Minimum of (In-block EIRP – 40) dBm / 5 MHz and 21 dBm / 5 MHz per antenna	Minimum of (In-block EIRP – 43) dBm / 5 MHz and 15 dBm / 5 MHz per antenna

The transitional limits do not apply to unsynchronised TDD blocks (these blocks are covered by the baseline limits). They also do not apply below 3400 MHz or above 3800 MHz.

A separate set of EIRP limits are defined for the guard bands and duplex gap in the FDD plan and these are presented below.

Table 2-3: Guard band power limits for FDD frequency plan

Frequency range	3400 – 3410 MHz	3490 – 3500 MHz	3500 – 3510 MHz	3590 – 3600 MHz
Guard band power limit	-34 dBm / 5 MHz EIRP per cell	-23 dBm / 5 MHz per antenna port	Minimum of (In-block EIRP – 43) dBm / 5 MHz and 13 dBm / 5 MHz per antenna	Minimum of (In-block EIRP – 43) dBm / 5 MHz and 13 dBm / 5 MHz per antenna

In the case of overlap between the transitional and guard bands, the transitional EIRP limits are applicable.

In order to protect any military radiolocation systems (radars) operating below 3400 MHz two additional baseline limits are defined in ECC Report 203 for both FDD and TDD blocks. Depending on whether there are military radiolocation receivers deployed in Ireland in the band below 3400 MHz an EIRP limit of either -50 dBm/MHz or -59 dBm/MHz can be used depending on the level of protection required for the radars.

2.2.3 Benefits of Synchronisation

ECC Report 203 as noted in Table 2-1 defines two different masks – the restrictive mask for non-synchronised co-existence and the permissive mask for synchronised. The advantage of using synchronisation is the increased mean field strength that may be used without coordination at the border between mobile / fixed communication networks. This is clearly demonstrated in ECC Recommendation (15)01 which provides in Annex 1 the following requirements:

- TDD systems can be used without coordination if the mean field strength of each cell produced by the base station does not exceed a value of 32 dBµV/m/5 MHz at a height of 3m above ground level at the border, and
- If the TDD systems are synchronised the value is 67 dBµV/m/5 MHz at a height of 3m above ground level at the border.

This means that with synchronisation of networks either side of a border the number of base stations that will require detailed coordination could be substantially reduced. Another advantage of synchronisation is it provides spectrum efficiency benefits. In the case of un-synchronised TDD base stations it may be necessary to define, in addition to the in-block and out-of-block power levels, frequency separations (guard bands) between the two adjacent operators, lower power levels in certain frequency blocks and require the use of internal guard bands.

There are already examples of network deployments where TDD operators' networks are synchronised and these are based on TD-LTE frame configuration 2 which supports a 3:1 downlink / uplink ratio. This, we understand, reflects current traffic volumes and could be the default if operators cannot agree on a synchronised frame structure.

Further information is provided in Appendix F and also WP2 report where information is provided on the Ofcom decision on synchronisation.

2.2.4 User Terminal In-block power limits

ECC Report 203 provides an in-block EIRP limit of 25 dBm/5MHz for the user terminals. However in EC Decision 2014 it is noted that "Member States may relax the limit of 25 dBm for fixed terminal stations provided that protection and continued operation of other existing use in the 3400 – 3800 MHz band is not compromised and cross-border obligations are fulfilled". This means ComReg has the option to increase the in-block EIRP limit for user terminals which could be beneficial noting the current prevalence of fixed networks in Ireland.

While the use of 25 dBm/5MHz to limit in-band emissions from mobile user terminals may be appropriate a more relaxed limit may have to be considered for fixed and nomadic user terminals with directional antennas. A review of limits proposed in various references is provided below.

- **ECC Recommendation (04)05**[7] provides guidelines for accommodation and assignment of multipoint fixed wireless systems in 3.4 – 3.8 GHz. In Annex 2, the maximum EIRP within a block is specified as 50 dBm/MHz for outdoor terminal stations. The maximum power to the antenna is limited to 43 dBm/MHz. Indoor terminals have an EIRP limit of 42 dBm/MHz.
- **Ofcom's UK Interface Requirements 2015.1 to 2015.3**[8] outlines requirements for operation within the UK in the 3400 – 4009 MHz band. The maximum in-block EIRP is specified as 50 dBm/MHz for fixed and nomadic outdoor terminals. The EIRP limit for fixed and nomadic indoor terminals is 42 dBm/MHz.
- **ITU-R Report S.2199 (11/2010)**[9] is the analysis of compatibility between FWA and FSS in the 3400 – 4200 MHz band. In the report, the representative terminal station power and antenna gain values are assumed to be 26 dBm + 17 dBi for fixed outdoor, 26 dBm + 5 dBi fixed indoor, 22 dBm + 5 dBi for nomadic terminals. For all cases, 1 dB feeder loss and 7 MHz channel bandwidth are also assumed.

[7] Guidelines for Accommodation and Assignment of Multipoint Fixed Wireless Systems in Frequency Bands 3.4 – 3.6 GHz and 3.6 – 3.8 GHz

[8] Spectrum Access in the 3400 – 4009 MHz Band, UK Interface Requirements 2015.1 to 2015.3, December 2011

[9] Studies on Compatibility of Broadband Wireless Access Systems and Fixed Satellite Service Networks in the 3400 – 4200 MHz band, November 2010

- **ECC Report 100**[10] provides a compatibility analysis between BWA and other services. In the report, it is assumed that the rooftop fixed terminal EIRP is 42 dBm (22 dBm + 20 dBi), the window fixed terminal EIRP is 32 dBm (22 dBm, + 10 dBi),the indoor fixed terminal EIRP is 31 dBm (22 dBm + 9 dBi) and the nomadic terminal EIRP is 25 dBm (20 dBm + 5 dBi)
- ITU-R and ECC Report assumptions are lower (which is expected as these are representative values rather than maximum levels) but not very far off from ECC Rec and UK IR limits.

It is worth noting that the limits specified in ECC Recommendation (04)05 and Ofcom Interface Requirements are in agreement. The EIRP assumptions of the ITU-R and ECC Reports are lower. This is expected as these are representative values for the modelling analysis rather than the maximum levels given in ECC Recommendation (04)05 and Ofcom Interface Requirements.

2.3 Cross border Coordination Thresholds

2.3.1 Introduction

There is currently a Memorandum of Understanding (MoU) in place between ComReg and Ofcom to limit cross border interference in the 3.6 GHz band. In ECC PT1, an ECC recommendation has been generated to address cross-border coordination issues in both the 1452 – 1492 MHz and 3400 – 3800 MHz. These are described further below.

2.3.2 Current MoU

The current coordination threshold level is *24 dBuV/m in 1 MHz* bandwidth (equivalent to *31 dBuV/m in 5 MHz*). The threshold level is applicable to a single transmitter and needs to be satisfied at 10 metre height (a.g.l.) and 15 km distance from the border or coastline[11].

The prediction of propagation needs to be based on ITU-R Rec.452 for 10% of time.

2.3.3 ECC Recommendation (15) 01

In ECC PT1, a cross border correspondence group was set up to draft a new ECC Recommendation for L-band (i.e. 1452 – 1492 MHz) and C-band (i.e. 3400 – 3800 MHz) cross border coordination among MFCN. The ECC Recommendation has been approved and published (ECC Recommendation (15)01)[12] and includes the following mean field strength threshold levels for the 3.6 GHz band.

- *32 dBuV/m in 5 MHz* per cell at 3 m height at the border when:
    - Unsynchronised TDD systems are deployed;

[10] Compatibility Studies in the Band 3400 – 3800 MHz between Broadband Wireless Access Systems and Other Services, February 2007

[11] ComReg 10/55, July 2010

[12] See http://www.erodocdb.dk/doks/doccategoryECC.aspx?doccatid=2

- A system operates in non-preferential blocks; and
  - FDD systems interfere with TDD systems in 3400 – 3600 MHz.
- *67 dBuV/m in 5 MHz* per cell at 3 m height at the border and *49 dBuV/m in 5 MHz* per cell at 3 m height at 6 km from the border inside the neighbouring country when:
  - Synchronised TDD systems are deployed;
  - A system operates in preferential blocks; and
  - FDD systems interfere with FDD systems in 3400 – 3600 MHz.

When the block size is different from 5 MHz a factor of *10 log (block size / 5 MHz)* needs to be added to the above thresholds.

It is stated that, if terrain data is available interference field strength predictions should be based on ITU-R Rec.452. Threshold levels are required to be satisfied at 90% of locations considered. Otherwise, ITU-R Rec.1546-5[13] needs to be employed for 50% of locations and 10% of time using a receiver height of 3 m. When a greater accuracy is required and terrain and clutter data are available, more detailed area calculations around a transmitter are recommended.

When the field strength thresholds are not satisfied, cross border coordination is required. The recommendation includes an annex where a list of parameters required for the coordination procedure is provided. To coordinate LTE-based networks, Preferential Physical Layer Cell Identities (PCIs) are required. The recommendation also provides a method on how available PCIs should be apportioned and used in European countries. In addition to the PCI coordination, a further annex is included, to outline guidance on the use of "demodulation reference signal" and "physical random access channel" coordination for LTE-based systems.

[13] However it is noted that ITU-R Rec. 1546 does not cover the 3.6 GHz band.

3 Co-existence Analysis Approach

The first step of the analysis is to derive appropriate field strength coordination threshold levels based on representative receiver characteristics. These threshold levels are then used to examine the impact of interference for different scenarios including

- MFCN / FWALA,
- synchronised TDD / unsynchronised TDD / FDD,
- macro / micro / pico / femto base station networks,
- urban / rural deployments.

The impact assessment is largely based on deriving areas where a given level of coordination threshold is exceeded. The implications of various mitigation measures are explained. Furthermore, the implications of cross border interference are investigated using threshold levels outlined in the preceding section in example deployment scenarios.

To be consistent with the work already undertaken within CEPT, parameters assumed in this study for MFCN are largely based on those given in ECC Report 203 where adjacent band co-existence requirements are investigated.

3.1 Field Strength Thresholds

Three different coordination threshold levels have been considered;

- *6 dB below the victim receiver noise floor:* This was adopted in ECC Report 203 and implies the victim receiver can only tolerate 1 dB loss in its fade margin due to interference. This situation might arise when the victim link is faded due to a propagation phenomenon and/or the victim link established is towards the edge of the coverage area.
- *The receiver noise floor:* This is a less stringent requirement and assumes that the maximum interference can rise up to the victim receiver noise floor which implies 3 dB loss in the victim link fade margin.
- *6 dB above the victim receiver noise floor:* This is the least stringent threshold and assumes that the victim link operates in favourable conditions and can tolerate interference 6 dB greater than its noise floor which implies 7 dB loss in the link fade margin.

3.2 Impact Assessment

The impact assessment has been implemented by calculating areas affected around interfering transmitters. Plum's in-house spectrum management tool (ASSET) has been used to derive interference contours representing assumed coordination thresholds by taking account of terrain features. The tool includes an ITU-R Recommendation 452 implementation which contains a prediction method for the evaluation of interference between stations on the surface of the Earth at frequencies from about 0.1 GHz to 50 GHz. In the modelling, it is assumed that coordination threshold levels need to be satisfied at 90% of locations for 90% of time.

Further analysis has been implemented using CEPT interference analysis tool SEAMCAT to calculate deployment distances that would be required from the border to meet the assumed threshold levels under pessimistic assumptions (e.g. no terrain and other mitigation techniques).

The modelling results aim to show the implications of adopting assumed threshold levels at the regional border when defining the regulatory framework for the new licensing regime.

3.3 Practical radio planning and deployment considerations

It is important to recognise that the radio planning work done by operators will need to be able to accurately predict the wanted service level and the interference level into neighbouring areas. The main differences between the operator's radio frequency (RF) planning and the calculations set out here are likely to be that the operators' calculations will:

- use actual equipment characteristics (ERP, Rx Threshold etc.);
- use actual antenna patterns;
- use different propagation models;
- model the effect of buildings, vegetation etc. (clutter); and
- use propagation models tuned by field measurements.

Practical base station antennas available in the 3.6GHz band are available with upper sidelobe suppression which exceeds that detailed in ITU-R1336. This should enable additional interference suppression by using antenna downtilt.

Propagation models used by operators are likely to model the clutter environment. Some systems will use generic land use classes and building or vegetation heights. Other systems, particularly in urban areas, may explicitly model the effect of individual buildings. The effect of clutter losses in general will be to increase the attenuation on Base Station to User Equipment paths, as the User Equipment will often be below the clutter height. Similarly the attenuation on low sited micro and pico Base Station to Base Station paths may also be increased.

The exploitation of more detailed prediction models backed by field measurements may give additional opportunities to design coverage in such a way as to limit unwanted interference into neighbouring areas.

In addition there are a range of mitigation factors that might be implemented to minimise co-channel interference into neighbouring areas and in this report we consider how these might facilitate practical deployments close to the regional borders.

4 Modelling Parameters

In this section, assumed parameter values for the interference modelling are provided.

4.1 Base Station Parameter Values

MFCN modelling parameters are largely based on assumptions made in ECC Report 203. The following table outlines assumed values used in the analysis.

Table 4-1: MFCN base station modelling parameters

Parameter		Assumed Value				Notes
		Macro	Micro	Pico (Indoor)	Femto (Indoor)	
Transmit Power (dBm/5MHz)		43	35	24	20	These values are the same as those used in ECC Report 203 to calculate adjacent band co-existence conditions in the form of block edge masks.
Feeder Loss (dB)		0	0	0	0	
Antenna Gain (dBi)		17	6	0	0	
Effective Antenna Height (m)		30 / 150	6	3	1	
Noise Figure (dB)		5	8	13	13	The macro base station with 150 m effective height is used to represent impact of interference from hilltop transmitters.
Antenna Downtilt (deg)		6	0	0	0	
Antenna Pattern (Rec.1336)		Sector with Peak Sidelobes (3 dB Hor BW= 65 deg)	Omni with Peak Sidelobes	Isotropic	Isotropic	
Interference Criteria (dBm/5MHz) (dBµV/m/5MHz)	I = N – 6	-108 (28)	-105 (37)	-100 (48)	-100 (48)	Three threshold levels corresponding to 1 dB, 3 dB and 7 dB loss in the victim link are chosen to capture the impact of interference in different victim link conditions. Note that power level is at the receiver input, field strength is at a reference point before antenna.
	I = N	-102 (34)	-99 (43)	-94 (54)	-94 (54)	
	I = N + 6	-96 (40)	-93 (49)	-88 (60)	-88 (60)	

ComReg provided data on FWALA systems currently occupying the 3.6 GHz band. It is noted that a mix of fixed WiMAX (802.16d), mobile WiMAX (802.16e) and Docsis technologies are currently used. There are also plans for TD-LTE upgrade.

The data indicates that WiMAX base stations are macro with a typical gain value of 17 dBi. These base stations mostly use 3-sector (25%) and 4-sector (58%) antennas. An EIRP of 60.5 dBm in

10 MHz channel is the most representative value. It is further noted that 83% of antenna mast heights are less than 30 m above ground level and 83% of the site plus mast heights are less than 150 m above sea level.

Based on data provided by ComReg, the coordination threshold for a WiMAX base station receiver is -106 dBm/10 MHz at the victim base station receiver input. This is based on a maximum allowed interference of 6 dB below the receiver noise floor of -100 dBm/10MHz. For an assumed antenna gain of 12 dBi at a 6-degrees downtilted receiver antenna, the figure of -106 dBm/10 MHz at the victim base station receiver input translates into 30 dBμV/m/10 MHz at a reference point before the receiver antenna at 3.6 GHz.

A representative EIRP for a Docsis base station transmitter, from the data provided, is 37 dBm in a 6 MHz downlink channel. Docsis base stations use 3 or 4 sector macro antennas with a typical 13 dBi gain. While typical antenna masts are 20 m above ground level the site plus mast heights are typically 350 m above the sea level.

The example Docsis link budget provided by ComReg indicates that the uplink channels are configured to be 3.2 MHz wide and the base station receiver noise floor is -105 dBm. Assuming that the maximum allowed interference is 6 dB below the receiver noise floor and a 6-degrees downtilted receiver antenna has a gain of 8 dBi the maximum interference field strength threshold is 29 dBμV/m/3.2 MHz.

The table below summarises the FWALA system parameters assumed for the analysis.

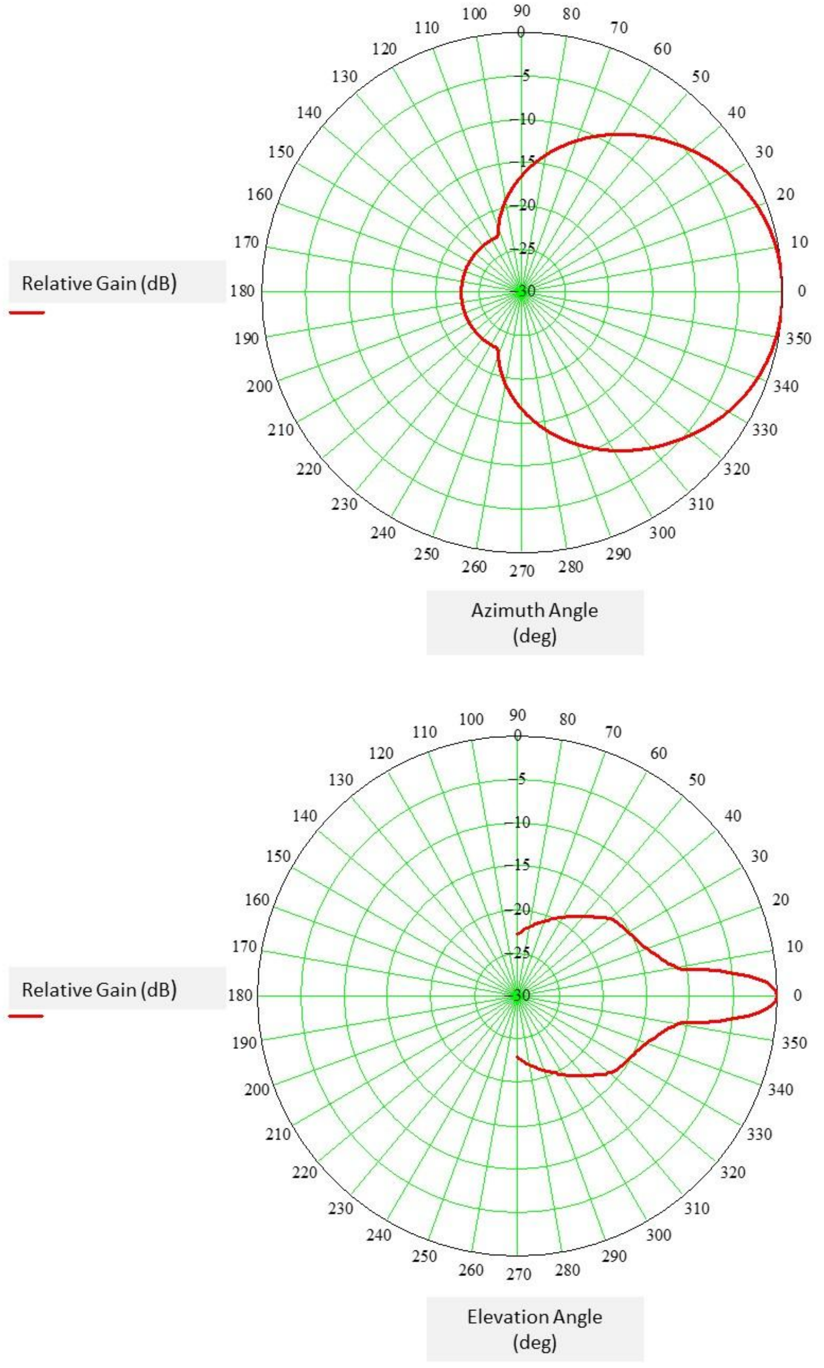
Table 4-2: FWALA base station modelling parameters

Parameter	Assumed Value
Transmit Power	43.5 dBm in 10 MHz (WiMAX) 37 dBm in 6 MHz (Docsis Downlink)
Antenna Gain (dBi)	17 (WiMAX) 13 (Docsis)
Effective Antenna Height (m)	30 / 150 (WiMAX) 20 / 350 (Docsis)
Antenna Downtilt (deg)	6
Antenna Pattern (Rec.1336)	Sector with Peak Sidelobes (3 dB Hor BW= 65 deg)
Interference Criteria (power level at the receiver input, field strength at a reference point before antenna)	-106 dBm / 30 dBμV/m in 10 MHz (WiMAX) -111 dBm / 29 dBμV/m in 3.2 MHz (Docsis Uplink)

4.1.1 Antenna Patterns

Generic antenna patterns defined in ITU-R Recommendation 1336 have been used to represent base station antennas. The following figure illustrates the assumed horizontal and vertical antenna patterns for the sector antenna.

Figure 4-1: Horizontal and vertical antenna patterns for sector antenna



4.2 User Terminal Parameter Values

Both fixed and mobile user terminal (UT) can be deployed. The table below summarises modelling parameters assumed in this study.

Table 4-3: User terminal modelling parameters

Parameter		Fixed UT	Mobile UT	Notes
EIRP (dBm/5MHz)		25		Assumes value in EC Decision 2014/276/EU is specified
Antenna Gain (dBi)		15	0	Directional antenna gain is based on an example Stella Doradus Planar antenna designed for 3.6 GHz band.
Antenna Height (a.g.l.) (m)		3	1.5	
Antenna Pattern		Directional with front to back ratio of 25 dB	Isotropic	Front to back ratio is based on an example Stella Doradus Planar antenna designed for 3.6 GHz band.
Noise Figure (dB)		9 dB		ECC Report 203
Interference Criteria (dBm/5MHz) (dBµV/m/5MHz)	I = N – 6	-104 (29) (54)	-104 (44)	Power level refers to the receiver input while field strength is at a reference point before antenna. For each assumed criterion, two field strength values are calculated for fixed UT scenarios where UT antenna is assumed to point towards and away from the base station.
	I = N	-98 (35) (60)	-98 (50)	
	I = N + 6	-92 (41) (66)	-92 (56)	

4.3 Propagation Modelling Assumptions

As noted earlier, ITU-R Recommendation P.452 has been used to model propagation effects in calculating the interference power at a given distance from an interfering base station. The basis for using this model is that it is the proposed propagation model for the assessment of interference between networks deployed in neighbouring countries and its prediction method covers the 3.6 GHz band.

The current cross-border agreement with the UK is based on satisfying coordination threshold for 90% of time (i.e. Rec.452 path loss predictions not exceeded for 10% of time). ECC Recommendation (15)01 on the cross border coordination for MFCN in the 3.6 GHz bands also includes a requirement for 90% of the receiver locations at the border to meet the threshold[14]. The models within Rec.452 are designed to calculate propagation losses not exceeded for time percentages over the range 0.001 - 50%.

[14] In Annex 2 of ECC/REC/(15)01 it says "if 10% of predicted values [at receiver locations within the neighbouring country] exceed the threshold the station shall be required to be co-ordinated".

The assumptions related to interference path propagation modelling are summarised in the table below.

Table 4-4: Propagation related assumptions

Parameter	Assumed Value	Notes
Operating frequency (MHz)	3600	
Location Variability Margin (dB)	7 (based on normal distribution with 5.5 dB standard deviation)	Calculations include a location variability margin of 7 dB to ensure that coordination threshold levels can only be exceeded at 10% of locations at the calculated distance from the interfering BS transmitter.
Building Penetration Loss (dB)	18	In line with ECC Report 203 assumptions, this is applied to pico and femto base stations which are assumed to be deployed indoors.
Clutter Loss (dB)	10	This is applied to micro base stations which are assumed to be deployed below the clutter outdoors at 6 m height.
Propagation model	ITU-R Rec.452 (as implemented in CEPT SEAMCAT interference analysis tool)	The model is used with 10% of time, i.e. coordination threshold levels can only be exceeded for 10% of time at the calculated distance from the interfering BS transmitter.

5 Analysis

The potential for a mix of TDD and FDD deployment scenarios imply that interference paths between;

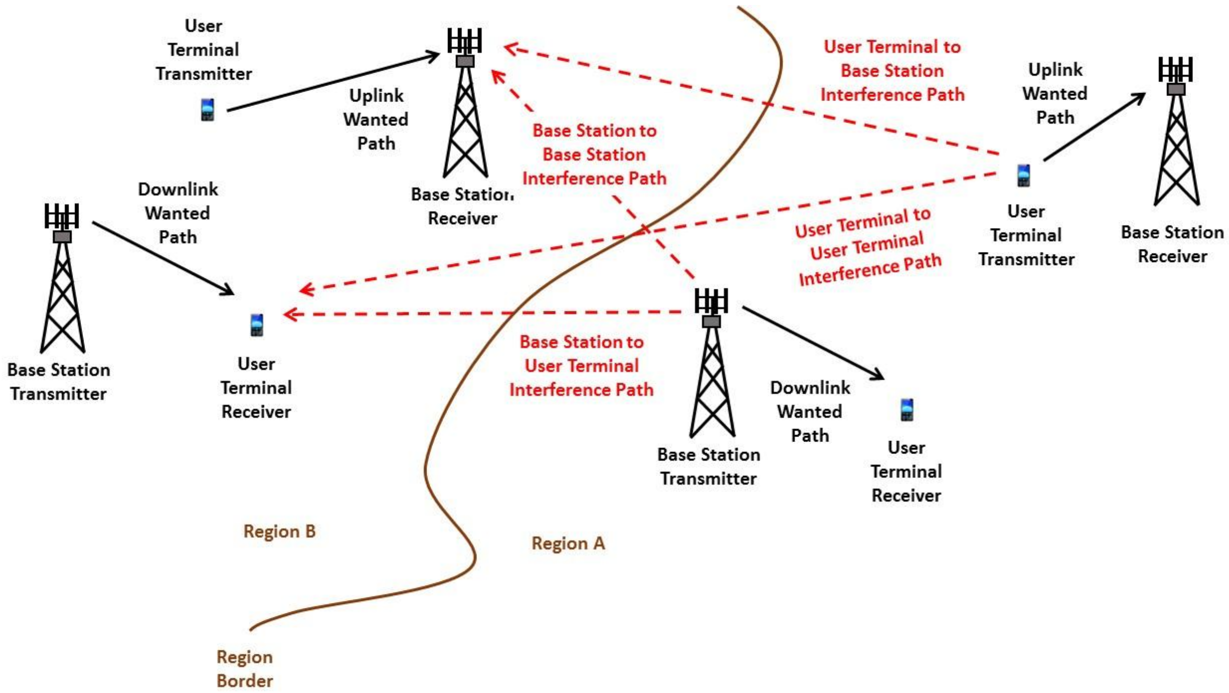
- base stations;
- base stations and user terminals; and
- user terminals

need to be considered.

5.1 Interference between Base Stations

When unsynchronised TDD networks are deployed, base station to base station, base station to user terminal, user terminal to base station and user terminal to user terminal co-channel interference paths can occur.

Figure 5-1: Interference from Region A into Region B when unsynchronised TDD networks are deployed



In such deployment scenarios, coordination threshold requirements will be mainly determined by base station to base station interference as the height and EIRP of base stations are higher than those of user terminals. Therefore, the co-channel coordination threshold conditions calculated for limiting base station to base station interference will also cover, by proxy, the coordination threshold requirements of base station to user terminal, user terminal to base station and user terminal to user terminal co-channel interference paths[15].

5.1.1 Coordination thresholds

A set of coordination thresholds based on system parameters are given in Table 4-1 and Table 4-2 for different victim base station receivers. The threshold levels are in the range of 27 – 60 dBµV/m/5MHz and each level is associated with a corresponding antenna height. However a commonly adopted approach used for defining a field strength limit is to associate a single height with the limit specified. A representative 10 m base station height is therefore assumed.

It is assumed that "*field strength thresholds in the range 30 – 60 dBµV/m/5MHz to be satisfied for 90% of time and 90% locations at 10 m height*" can be used to define generic co-channel coordination threshold requirements to accommodate different MFCN deployments.

5.1.2 Impact Assessment

Example sites in Ireland have been selected to undertake simulation modelling by incorporating Irish terrain data based on Shuttle Radar Topography Mission (SRTM) database into ITU-R Rec.452 model. The aim of the analysis is to show the impact of assumed thresholds by deriving representative interference areas centred on a typical interfering macro base station.

Plum's in-house spectrum management tool (ASSET), has been used to calculate the interference areas. The tool calculates signal strength at a distance from a given transmitter by taking account of terrain and antenna patterns.

Interference areas are defined by contours related to assumed coordination thresholds. At any location within the contour, it can therefore be assumed that there is the potential for interference at the victim base station receiver.

It can be seen from the examples below that the outcome can vary significantly depending on the terrain, the type and direction of pointing of the transmitter base station antenna(s) and the location of the receiving base station. It is also important to understand that the interference contours are interference predictions based on available terrain knowledge and provide an indication of the practical situation but it can be seen that with just an additional 10 dB of loss, which could be due to clutter, practical deployment locations or additional losses due to mitigation measures the geographic area within which a transmitter will have an impact on a receiver may be substantially reduced[16].

Note that further modelling has been undertaken using SEAMCAT analysis tool. Details of SEAMCAT analysis are provided in Appendix B.

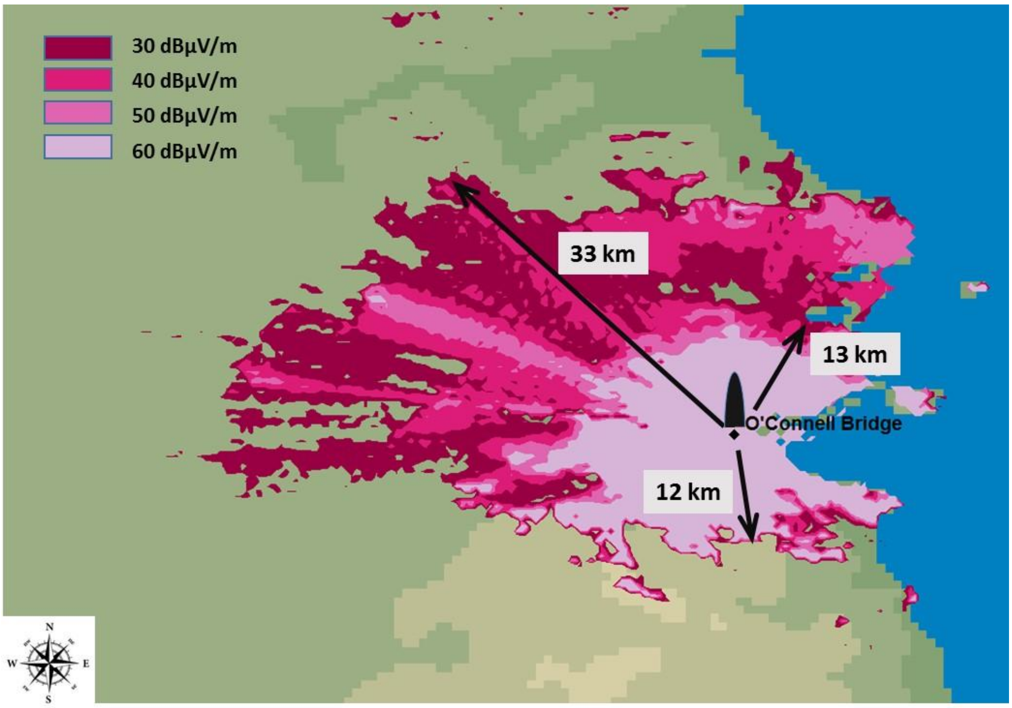
[15] In other words this effectively mean the co-existence requirements of other interference paths will be less stringent than those of base station to base station interference.

[16] For example in Example Scenario 1 the difference between 30 dBµV/m and 40 dBµV/m contours – relating to an additional 10 dB of propagation loss – is noticeably different.

Example scenario 1: Urban macro base station transmitter

The transmitter is assumed to be located near the O'Connell Bridge in Dublin. It is assumed that a 6-degrees downtilted sector transmitter antenna, with a 65 degrees horizontal 3 dB beamwidth and a 9.5 degrees vertical 3 dB beamwidth, is located on top of a building at 30 m above ground level. It is further assumed that the antenna is pointing towards the due north and EIRP is 60 dBm/5MHz. Interference contours are shown in the figure below.

Figure 5-2: Interference contours when an interfering macro base station pointing north is located near O'Connell Bridge (with terrain)

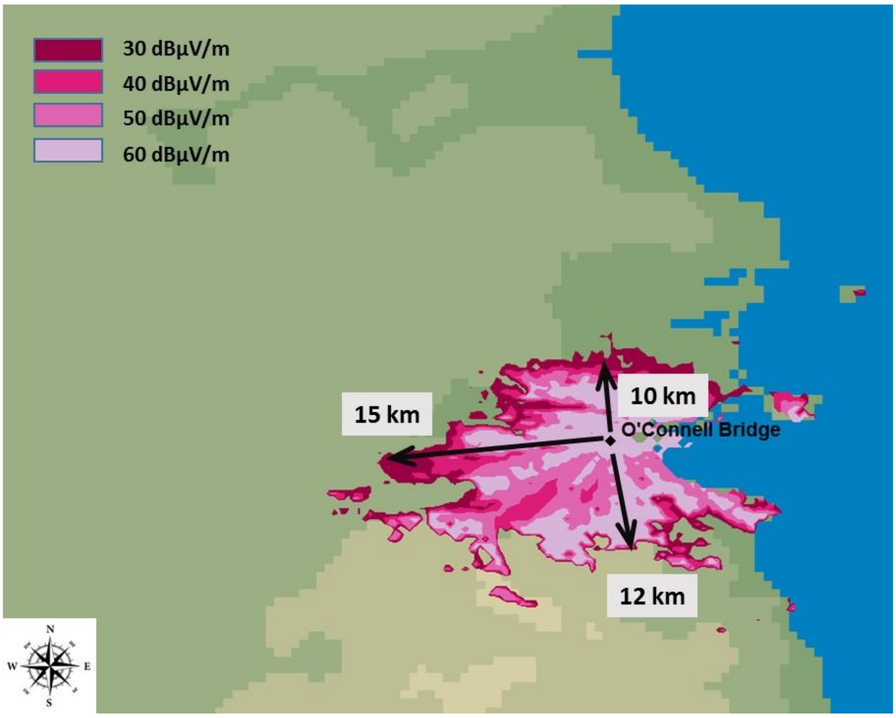


For the most stringent criterion (i.e. 30 dBμV/m/5MHz), the extent of the affected area is limited to 33 km in most directions from the location of the macro base station transmitter. Towards the south where the interference paths are from the back of the antenna, the area extends up to 12 km.

Example scenario 2: Urban micro base station transmitter

The analysis is repeated by replacing the macro base station with a micro base station assumed to be at 6 m above ground level using an omnidirectional antenna with an EIRP of 41 dBm.

Figure 5-3: Interference contours when an interfering micro base station is located near O'Connell Bridge (with terrain)

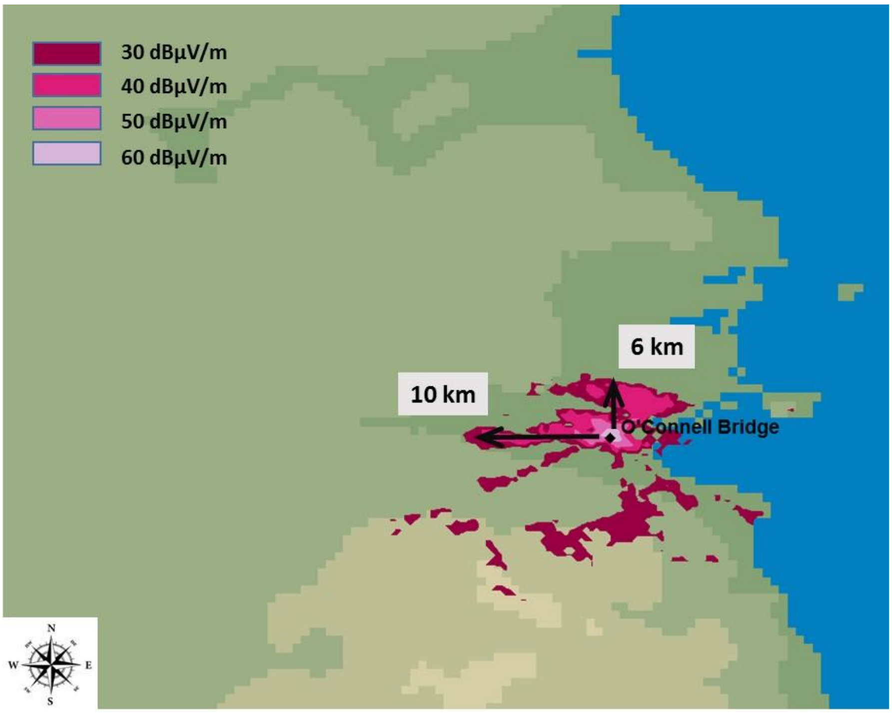


Compared to the macro base station scenario, the use of a lower antenna height coupled with a lower EIRP leads to an interference area extending up to 10 km radius to the north, 15 km to the west and 12 km to the south.

Example scenario 3: Urban pico base station transmitter

Interference contours for a pico base station transmitter are calculated. The transmitter is assumed to be at 3 m above ground level using an isotropic antenna with an EIRP of 24 dBm.

Figure 5-4: Interference contours when an interfering indoor pico base station is located near O'Connell Bridge (with terrain)



As can be seen, the contiguous area around the pico transmitter is reduced significantly compared to the macro and micro base station scenarios. There are however directions of interference area extending up to 10 km to the west. It should be noted that simulations take account of terrain features and clutter effects are likely to reduce the affected area further.

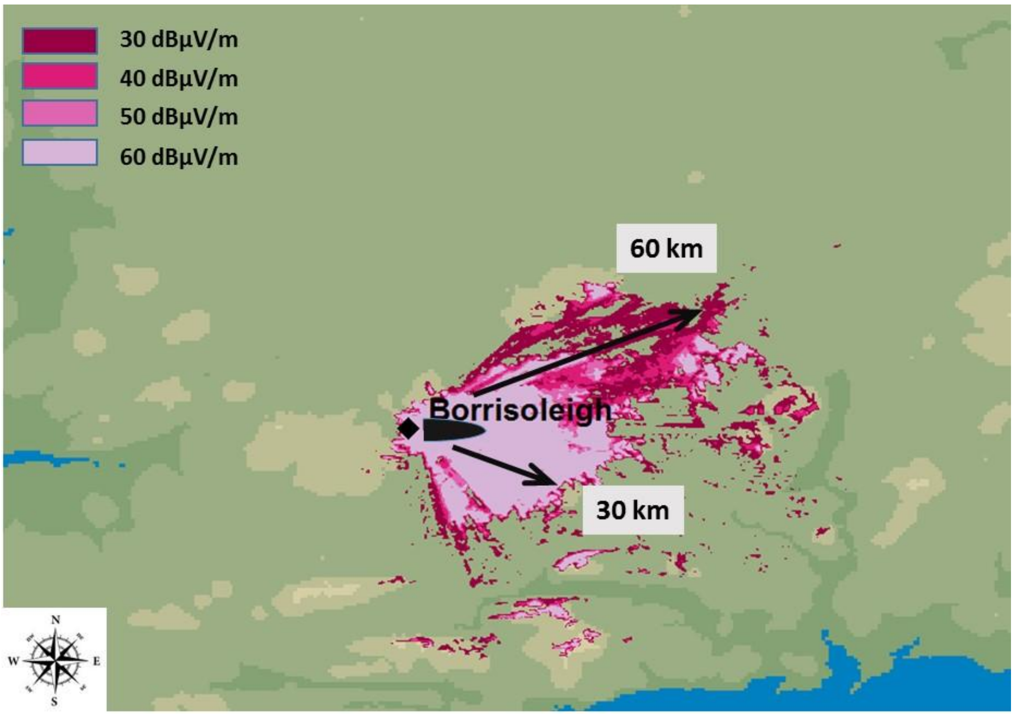
Example scenario 4: Rural macro base station transmitter

In this example, a macro transmitter is located at an elevated position (150 m above sea level) in Borrisoleigh town which is 100 m above sea level.

Figure 5-5: Borrisoleigh Scenario

It is assumed that the sector transmitter antenna is at a 10 m mast and pointing towards the town (4-degrees downtilted). EIRP is assumed to be 60 dBm/5MHz. Interference contours are illustrated in the following figure.

Figure 5-6: Interference contours when an interfering macro base station pointing east direction is located in Borrisoleigh (with terrain)



The results show that when an elevated position is chosen as a transmitter site the affected area can increase considerably. In this example, distances extend up to 60 km to the east of the transmitter where the antenna is assumed to be pointing.

5.1.3 Mitigation Measures

A number of practical measures can be applied to reduce the potential for interference from base stations located near the regional border into neighbouring areas. Such measures would be typically considered as part of the detailed network planning. Depending on the location and type of the base station transmitter (e.g. macro or micro) one or more of the following might be implemented to reduce the interfering signal across the regional border and so meet the required agreed field strength limit[17] and avoid the need for detailed co-ordination with the neighbouring operator. In some instances there will need to be a trade-off between the coverage that can be achieved from a base station against the potential for interference across the regional border.

- ***Base station transmitter positioning:*** The ideal approach is to locate a base station to take advantage of natural shielding which limits the transmissions in the direction of the regional border. The shielding could be provided for example by, in the case of small cells "burying" the transmitter in the clutter, or locating a base station slightly down one side of a hill. The benefit of shielding is very much dependent on terrain around the base station transmitter. For example, if an additional loss of 20 dB can be achieved due to shielding much of the area affected by interference in the O'Connell Bridge macro base station scenario (Figure 5-2) will be reduced from 33 km to 13 km which is the difference between the 30 and 50 dBμV/m/5MHz contours shown in Figure 5-2.
- ***Antenna pointing:*** In regional border areas, macro base station antennas can be directed away from the regional border. In this case, interference paths into adjacent areas originate from the rear lobes of the transmitter antenna and a typical antenna front to back ratio can be in the order of 20 – 25 dB. An example impact of antenna pointing can be seen in Figure 5-2 where the area affected from interference is reduced from 33 km to 12 km when comparing the interference contours to the north (where the main beam is pointing) and to the south (where interference is through the back of the antenna).

  Such approaches have been adopted by existing FWALA operators in border regions of Ireland to limit cross-border interference.

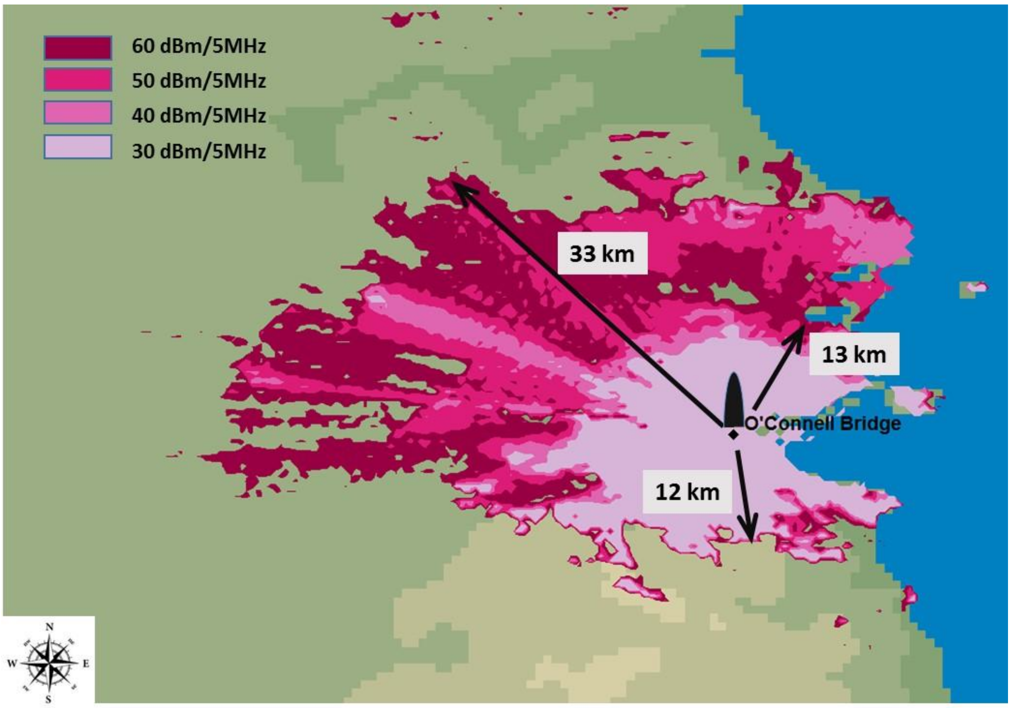
  In this study, cross border macro base station examples (see Section 5.5) assume that transmitters point away from the border. This typically results in reducing the interference area to within 10 km of the regional border.
- ***Antenna height:*** In regional border areas, the base station antenna height can be reduced to limit the area of interference. This might however reduce the base station's own coverage area and the operator might need to deploy more base stations to achieve the coverage target which would increase costs.

[17] This limit might be the one set by ComReg as part of the licence conditions or a mutually agreed limit agreed between the adjoining operators.

Transmit power and antenna techniques for limiting interference near regional borders

- ***Transmit power:*** It is also possible to limit the transmit power to minimise the area of interference near regional borders. As in the case of antenna height reduction, this may however reduce the base station coverage area leading to a requirement for an increased number of base stations. The following figure compares 30 dBµV/m/5MHz interference contours for different EIRP levels.

Figure 5-7: 30 dBµV/m/5MHz interference contours when an interfering macro base station pointing north is located near O'Connell Bridge and EIRP is varied (with terrain)

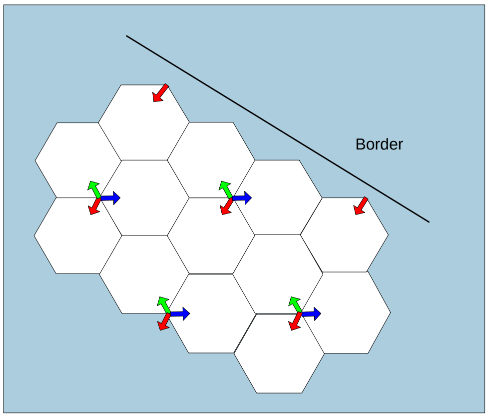


It is also worth noting that the combined effects of reduction in base station transmitter height and EIRP can be seen in the maps generated for the urban macro (30 m, 60 dBm/5MHz), micro (6 m, 41 dBm/5MHz) and pico (3 m, 24 dBm/5MHz) base station transmitters in Section 5.1.2 where corresponding interference areas are 33, 15 and 10 km to the regional border.

- ***Antenna downtilt:*** Antenna downtilt can be used to direct the main beam of the antenna downward to constrain interference into neighbouring regions. This can be particularly effective with high sites and high gain antennas with narrow vertical patterns. Care must be exercised when downtilting an antenna to ensure that antenna side or back lobes do not increase interference into areas behind or at the side of the antenna. In this study, scenarios with macro base stations assume 6 degrees antenna downtilt which leads to an additional antenna discrimination of approximately 5 dB in the vertical plane (see Figure 4-1).

- ***Antenna directivity:*** In scenarios where the aim is to provide a service for a population spread over a small geographic area near a regional border, it might be possible to deploy directional base station antennas to direct the emissions towards the target area while minimising spillage into the neighbouring regions. Directional antennas are available on the market ranging from 8° - 120° horizontal beamwidth. In the figure below it can be seen that base station sites near the border can be limited to use directional antennas.

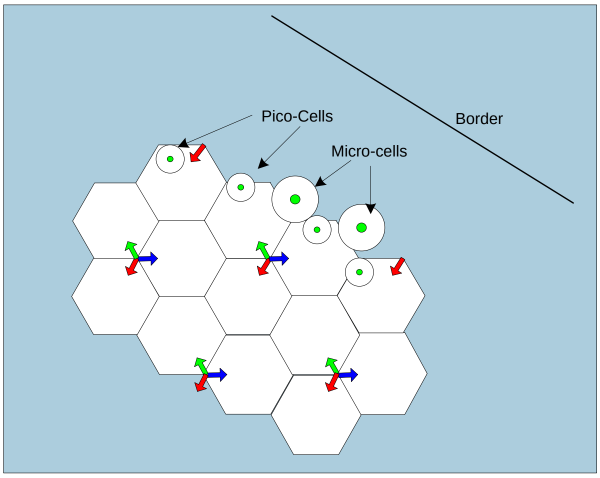
Figure 5-8: Cell cluster near border



In specific deployment scenarios, it may also be possible to use smart antennas relying on antenna beamforming techniques to provide a required antenna directivity. Smart antennas can be based on a phased array; where there are a number of pre-defined patterns and they can be switched according to the direction required, or an adaptive array; where the beamforming adapts and can be modified according to real time requirements. The phase array approach is more suited for fixed deployments while the adaptive array approach is more appropriate for mobile deployments.

- ***Heterogeneous base station deployment:*** Micro and pico base stations can be deployed near regional borders to minimise interference into neighbouring areas.

Figure 5-9: Heterogeneous base station deployment



- ***Antenna polarisation:*** The use of different antenna polarisations either side of the regional border could provide additional interference discrimination in the order of 5 to 10 dB depending on the path. However, this is only seen as a possible measure for fixed wireless access networks which use line of sight deployments and where the antennas use linear horizontal or linear vertical polarisations. The use of antenna polarisation would however limit the FWA base station capacity as polarisation diversity is likely to be the favoured type of MIMO, as conventional MIMO is less effective in a line of sight environment. In the case of cellular micro and smaller cells, where there is no line of sight, MIMO antennas use ± 45° polarisation to overcome the impact of signal scattering and de-polarisation. In this case antenna polarisation will also not be useful. In general antenna polarisation might not therefore be a preferred mitigation option.

- ***Synchronisation:*** When networks operating on either side of the regional border are synchronised (i.e. they use a common time reference and their frame structures are compatible) base station to base station interference paths are eliminated. In such scenarios, interference paths are between base stations and user terminals and would generally be expected to reduce the area over which there is the potential for interference. ECC Report 216 "Practical Guidelines for TDD networks synchronisation" provides further information and in Appendix F we provide a summary. It is not clear whether operators would mutually agree to implement synchronisation as it requires all operators to adopt the same fixed uplink and downlink ratio and so reduces the benefit of TDD in terms of adapting the uplink / downlink ratio to take account of changes in traffic patterns. The use of synchronisation is likely to require ComReg to consult and decide on an appropriate ratio, this is also discussed in section 2.2.3 above and further information is presented in Appendix F.

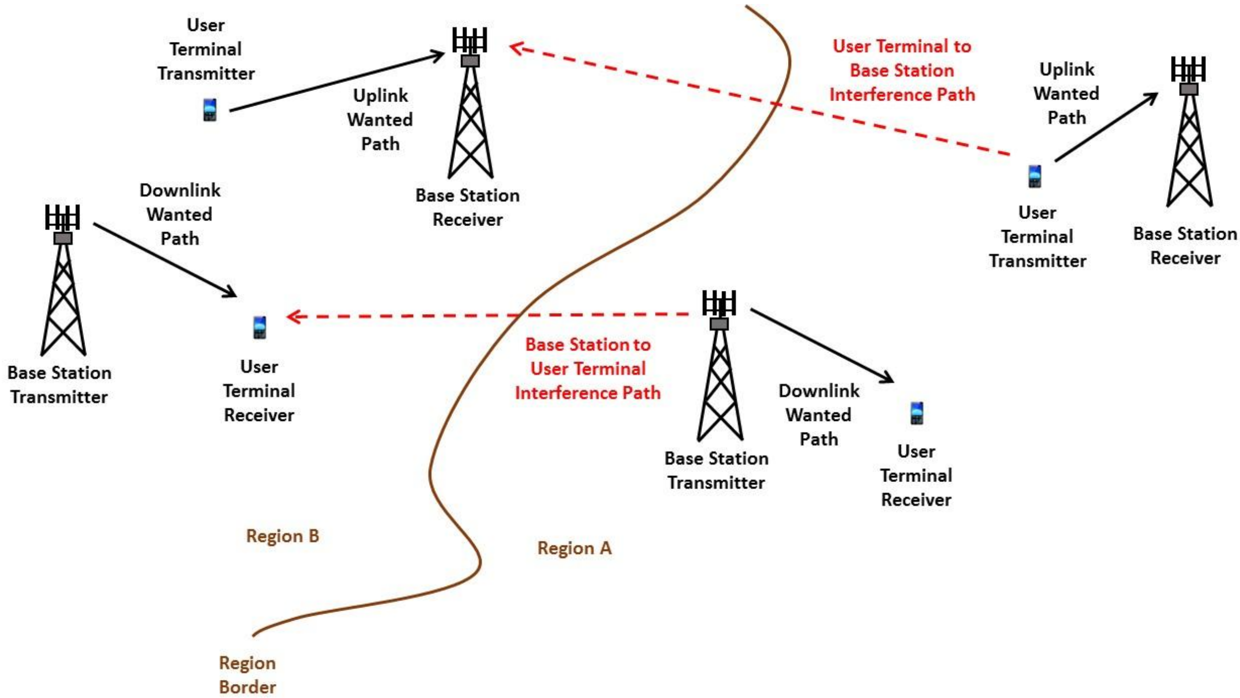
  In base station to user terminal interference situations where user terminals are at or below clutter height, the clutter loss can provide additional benefit. The implications of interference between base stations and user terminals are examined in the following section.

5.2 Interference between Base Stations and User Terminals

When synchronised TDD and/or FDD networks are deployed base station to base station and user terminal to user terminal interference paths do not arise. In such deployment scenarios, coordination threshold conditions will be driven by interference paths between base stations and user terminals across the regional border as shown in the figure below[18].

[18] Cross border base station to user terminal interference paths and vice versa will also occur for TDD non-synchronised deployments but in this instance base station to base station is the dominant consideration see Figure 5-1.

Figure 5-10: Interference from Region A into Region B when synchronised TDD and/or FDD networks are deployed



The benefits of synchronisation for geographically adjacent operation are scenario dependent. In the following sections, a number of examples are considered using interference predictions taking into account terrain. However in practice it is important to understand that in practical network planning there will be mitigating considerations such as:

- In the case of mobile terminal receivers they may be deployed in-doors or in the clutter so additional losses may apply reducing the distances required to the regional border.
- Also mobile terminal receivers are generally not at a single location over any considerable period of time so the probability of interference and the impact will be less than for fixed wireless access systems.
- When mobile receivers are on the edge of coverage, and most prone to interference from a neighbouring base station transmitter, it is likely that they will automatically use a different frequency as mobile terminals are multi-band devices.
- In the case of fixed terminal receivers they use directional antennas and there is the potential to locate them on a building to minimise interference from any existing base stations deployed in the adjacent regional area.

It is therefore anticipated that the use of synchronisation may, in some cases, allow for smaller separation distances than indicated by the example scenarios.

5.2.1 Coordination thresholds

When considering the interference between base stations and user terminals it is necessary to consider two different scenarios – base station into a user terminal and a user terminal into a base station so we need to define the coordination thresholds for both the base station and user terminal receivers.

User Terminal Receivers

A set of coordination thresholds based on system parameters are given in Table 4-3 for different victim user terminal receivers. The threshold levels are in the range of 29 – 66 dBµV/m/5MHz associated with assumed antenna heights. As stated earlier, a commonly adopted approach used for defining a field strength limit is to associate a single height, with the limit specified. A representative 3 m high user terminal receiver antenna is therefore assumed.

It is assumed that "*field strength thresholds in the range 30 – 65 dBµV/m/5MHz to be satisfied for 90% of time and 90% locations at 3 m height*" can be used to define generic co-channel coordination threshold requirements for base station to user terminal interference scenarios occurring in synchronised TDD and/or FDD network deployment scenarios.

Base Station Receivers

The impact of interference from fixed and mobile user terminal transmitters has been examined for the base station receiver coordination threshold range of 30 – 60 dBµV/m/5MHz identified in Section 5.1.1.

5.2.2 Impact Assessment

Simulation analysis has been undertaken for example sites.

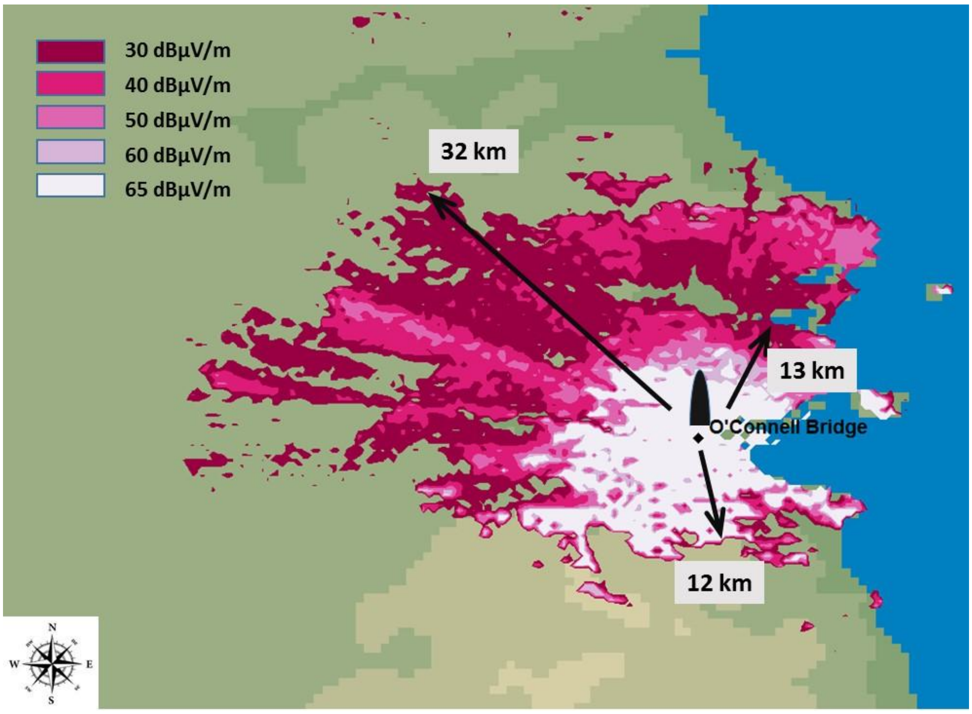
Note that further modelling has been undertaken using SEAMCAT analysis tool. Details of SEAMCAT analysis are provided in Appendix C.

Base Station to User Terminal Interference Scenarios

Example scenario 1: Urban macro base station transmitter

The following figure shows interference contours for the urban macro base station transmitter scenario where a 6-degrees downtilted base station transmitter is assumed to be located near the O'Connell Bridge in Dublin pointing towards the due north. EIRP is 60 dBm/5MHz.

Figure 5-11: Interference contours when an interfering macro base station pointing north is located near O'Connell Bridge (with terrain)

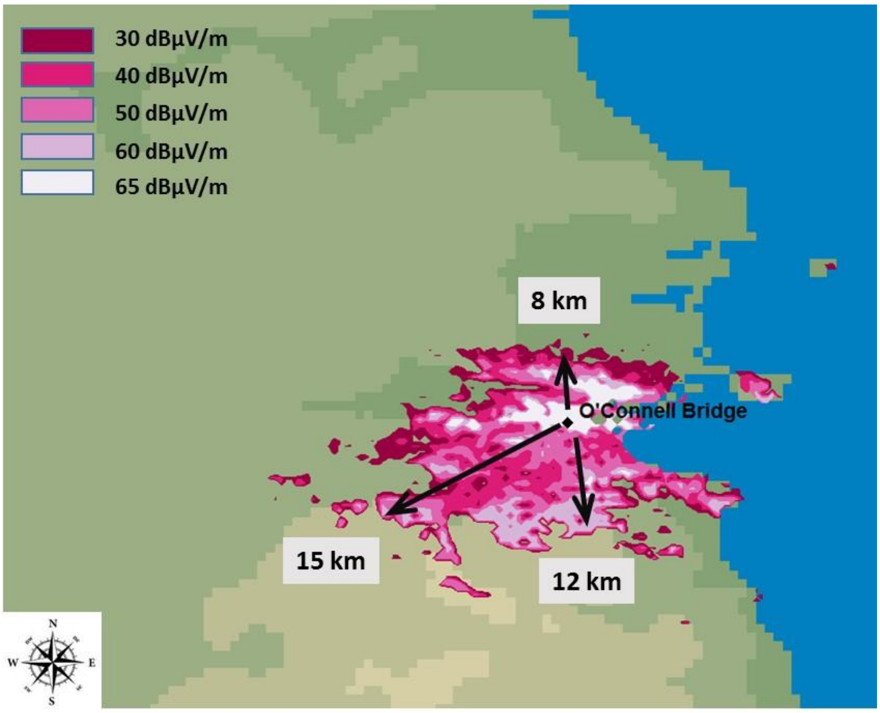


The use of 3 m reference height for base station to user terminal interference scenario reduces the overall interference area to some extent compared to the base station to base station interference scenario where the reference height is 10 m (see Figure 5-2). However, the maximum distances remain at similar levels.

Example scenario 2: Urban micro base station transmitter

Interference contours obtained for a micro base station assumed to be at 6 m above ground level using an omnidirectional antenna with an EIRP of 41 dBm are shown in the following figure.

Figure 5-12: Interference contours when an interfering micro base station is located near O'Connell Bridge (with terrain)

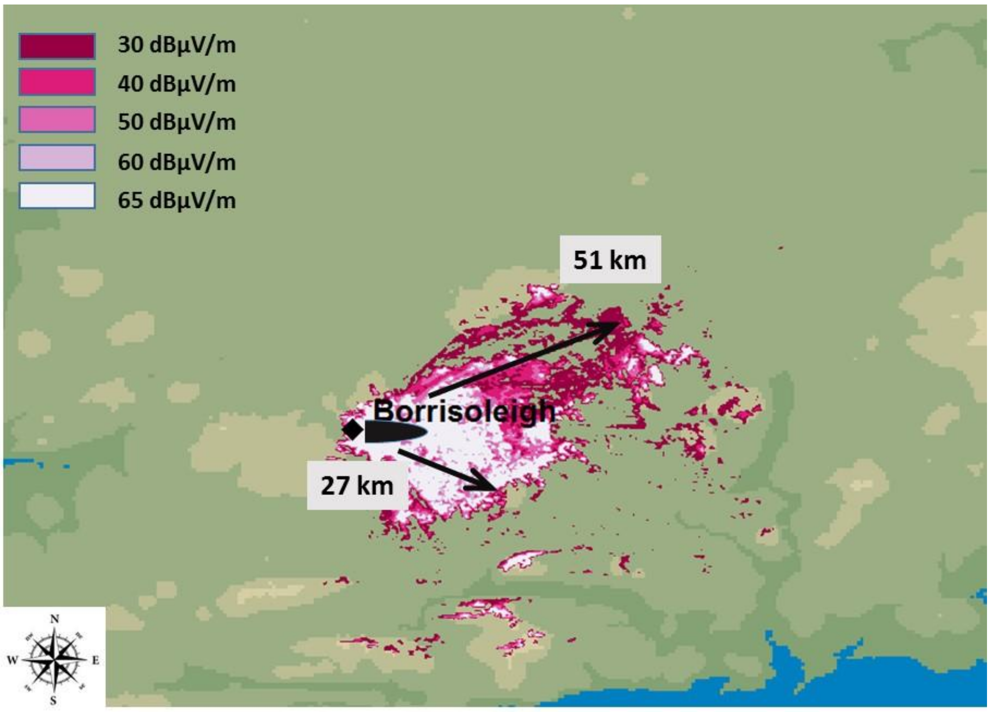


Similar to the previous scenario, the results show that while the overall interference area is reduced the maximum distances are at a similar level compared to the corresponding base station to base station scenario (see Figure 5-3). However no account is taken of possible factors such as clutter loss which could significantly reduce the distances presented in these scenarios.

Example scenario 3: Rural macro base station transmitter

The Borrisoleigh scenario has been re-examined by assuming that the coordination thresholds refer to 3 m reference height assumed to be representative of a user terminal receiver.

Figure 5-13: Interference contours when an interfering macro base station pointing east direction is located in Borrisoleigh (with terrain)



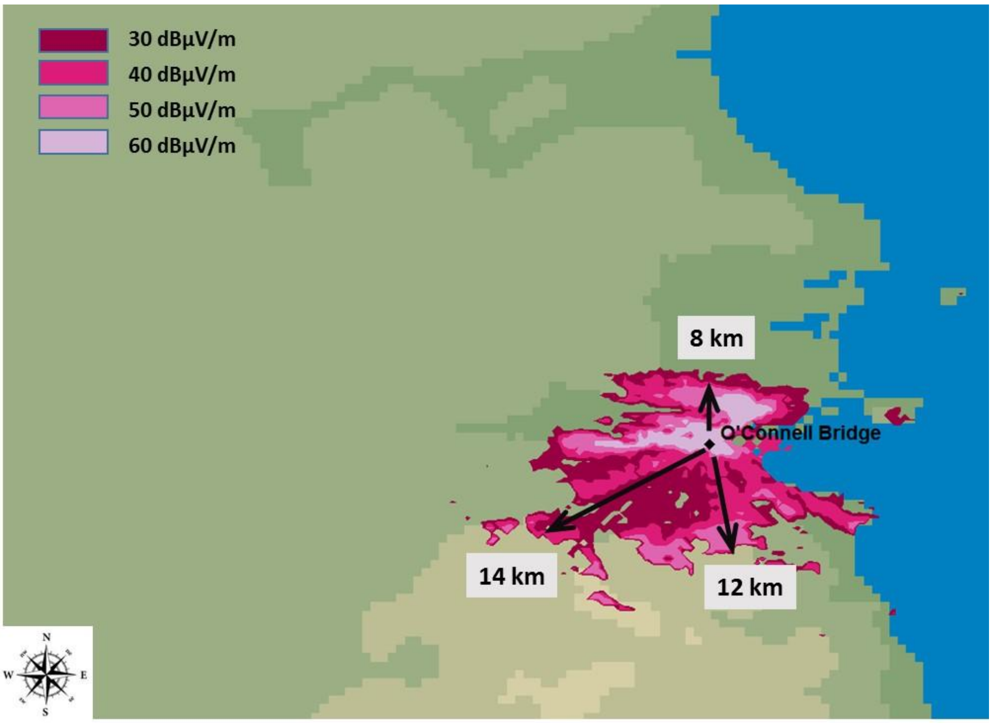
Compared to the corresponding base station to base station scenario (see Figure 5-6), there is a reduction in the overall area affected by interference. The maximum distances are also reduced by approximately 10%.

User Terminal to Base Station Interference Scenarios

Example scenario 1: Urban user terminal transmitter

A user terminal transmitter with an omnidirectional antenna is assumed to be near O'Connell Bridge. EIRP is 25 dBm/5MHz. The following figure shows the interference contours for field strength values in the range 30 – 60 dBµV/m/5MHz referenced to 10 m height above ground level.

Figure 5-14: Interference contours when an interfering user terminal with omnidirectional antenna is transmitting near O'Connell Bridge (with terrain)

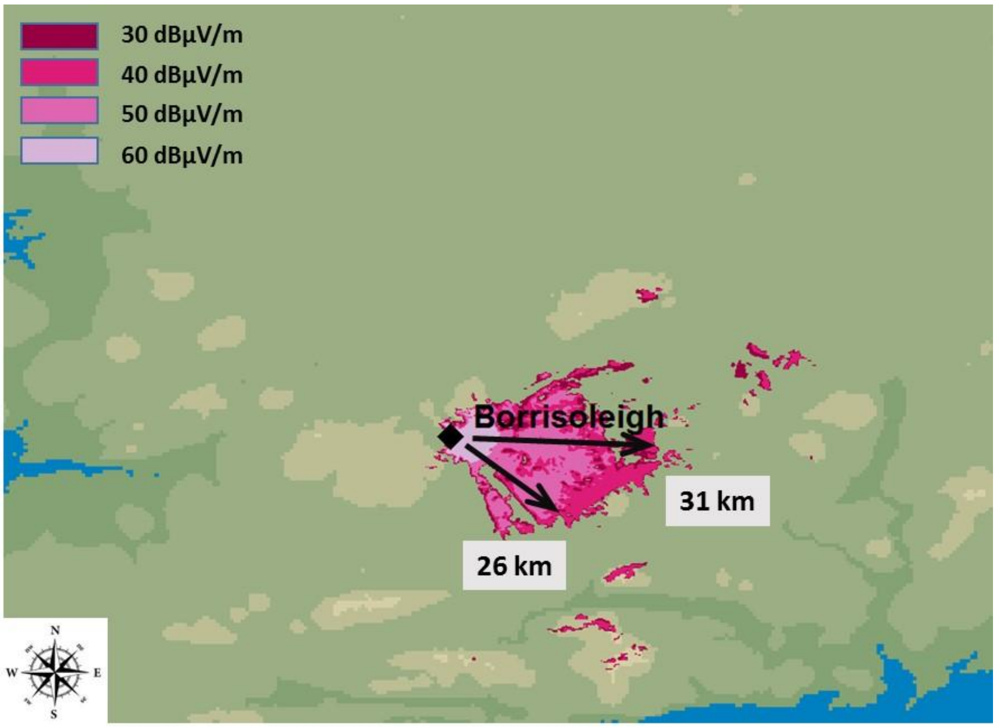


The contours indicate that areas are limited to 8 km from the transmitter location to the north. High ground towards south results in interference areas up to 14 km from the transmitter location. Compared to the urban macro base station to user terminal interference requirements (see Figure 5-11), the urban user terminal to base station requirements are considerably less stringent. On the other hand, calculated distances are similar to those obtained for the urban micro base station to user terminal interference scenario (see Figure 5-12).

Example scenario 2: Rural user terminal transmitter

The user terminal of the preceding scenario is assumed to be located near Borrisoleigh. Interference contours are shown in the following figure.

Figure 5-15: Interference contours when an interfering user terminal with omnidirectional antenna is transmitting near Borrisoleigh (with terrain)

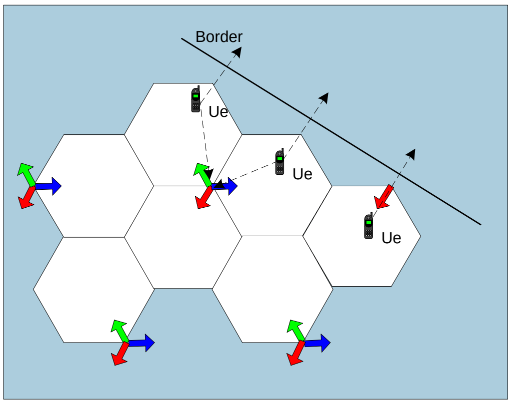


As can be seen, the interference contours are within 31 km of the transmitter location in most directions. Compared to the rural base station to user terminal scenario (see Figure 5-13), there is a considerable reduction in the overall area affected by interference and the maximum distance is also reduced considerably.

5.2.3 Mitigation Measures

Mitigation techniques identified in Section 5.1.3 can also be used to minimise interference between base stations and user terminals. In addition, automatic power control can be applied to the user terminal transmitters in the uplink where the system automatically adjusts the transmitted power so that the signal level at the base station is sufficient for the required performance. This level tends towards providing the average required throughput. If the user terminal is near the regional border there will be a risk of interference into neighbouring areas. This risk could be mitigated to some extent by adjusting the power control parameters.

Figure 5-16: User terminal interference risk



In the case of fixed networks, the use of directional user terminal antennas should reduce the risk of interference into neighbouring areas as they are expected to be pointing away from the regional border.

It is also worth noting that, as shown in the example scenarios examined in the preceding section, when synchronised networks are deployed on either side of the regional border the interference is likely to be dominated by the base station transmitters as these use higher power and are more elevated so the benefits associated with the use of power control and directional antennas at the user terminal may be limited in practice.

5.3 Interference between User Terminals

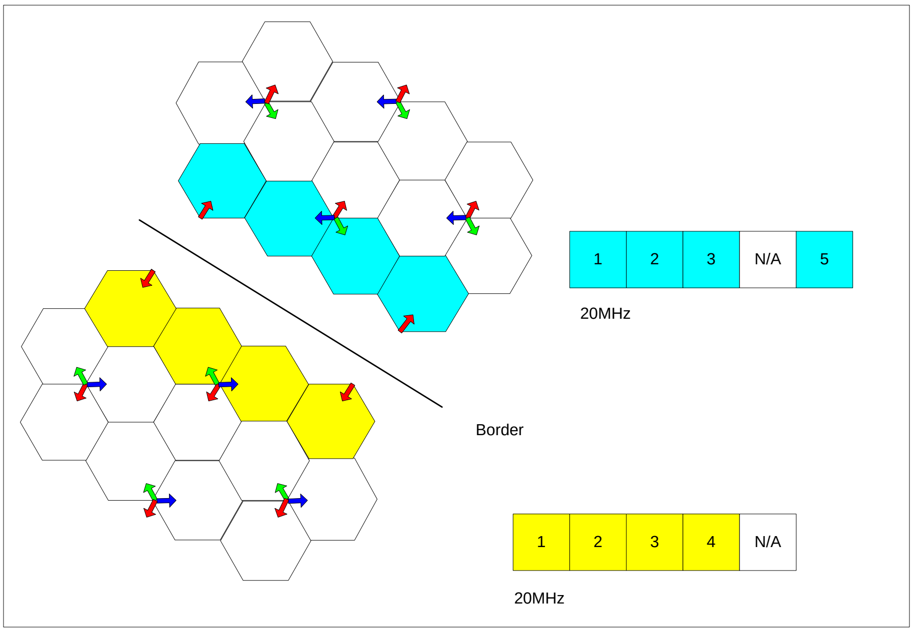
User terminal to user terminal interference paths can occur when unsynchronised TDD networks are deployed co-channel in adjacent geographic areas. Coordination threshold requirements of co-channel unsynchronised TDD networks will be determined by base station to base station interference paths and these requirements will minimise the interference potential between user terminals.

5.4 Other Options to Reduce Interference at the Border

An example scenario shown in the Figure 5-14 below assumes that two operators use the same 100MHz of radio spectrum in the 3.6 GHz band across their respective networks except at the border. In this arrangement, Operator 1 uses only the spectrum block 1, 2, 3 and 4 leaving spectrum block 5 unassigned in the border area. Operator 2 uses the spectrum blocks 1, 2, 3 and 5 leaving spectrum block 4 unassigned in the border area.

The advantage of this arrangement is that there will be less interference at the cell from the other network when using spectrum block 4.

Figure 5-17: Frequency assignments at the border



Also, in the case of LTE, cross-border agreements have been based on the use of codes - see Annex 5 in the ECC Recommendation (08)02, which was updated in April 2012, and describes the preferential physical-layer cell identities (PCI)[19] for LTE. PCI co-ordination is only required when channel frequencies are aligned independent of the channel bandwidth. There are 168 "unique physical-layer cell-identity groups" and within each PCI group there are three separate PCIs (making a total of 504 PCIs).

This approach might also be used for regional cross-border agreements although the disadvantage of such an approach is the cross-border agreements with UK are likely to define preferential and non-preferential PCIs so it may not be a solution in border areas. It is however noted that all PCIs are available in areas away from borders. Whilst PCI clashes will limit performance, PCI planning on its own will not mitigate interference.

5.5 Cross-border Interference Analysis

In Section 2.3, the current cross border threshold between the UK and Ireland and ECC Recommendation (15) 01 cross border thresholds are described. These are summarised in the following table.

[19] The physical cell ID is used by the UE (user equipment) to decode the physical layer data being transmitted by eNodeB. It consists of 2 synchronisation signals – primary PSS) and secondary (SSS). Ideally each cell would have its own cell ID but there are only 504 physical cell IDs so if a network has more than 504 cells the physical cell IDs will need to be repeated. Any cells that share a physical cell ID cannot be geographically close or they will interfere with each other.

Table 5-1: Cross-border coordination thresholds

Coordination threshold (dBµV/m/5MHz)			
31 (10 m height 15 km from the border)	32 (3 m height at the border)	49 (3 m height 6 km from the border)	67 (3 m height at the border)
to be satisfied for 90% of time and 50% of locations (MoU)	to be satisfied for 90% of time and 90% of locations (ECC Recommendation (15) 01)		

The implications of these threshold levels have been examined for a number of example sites near the border with Northern Ireland.

5.5.1 Impact Assessment

The analysis of example scenarios is provided below. Further examples are given in Appendix E of this report.

Also note that further modelling has been undertaken using SEAMCAT analysis tool. Details of SEAMCAT analysis is provided in Appendix D.

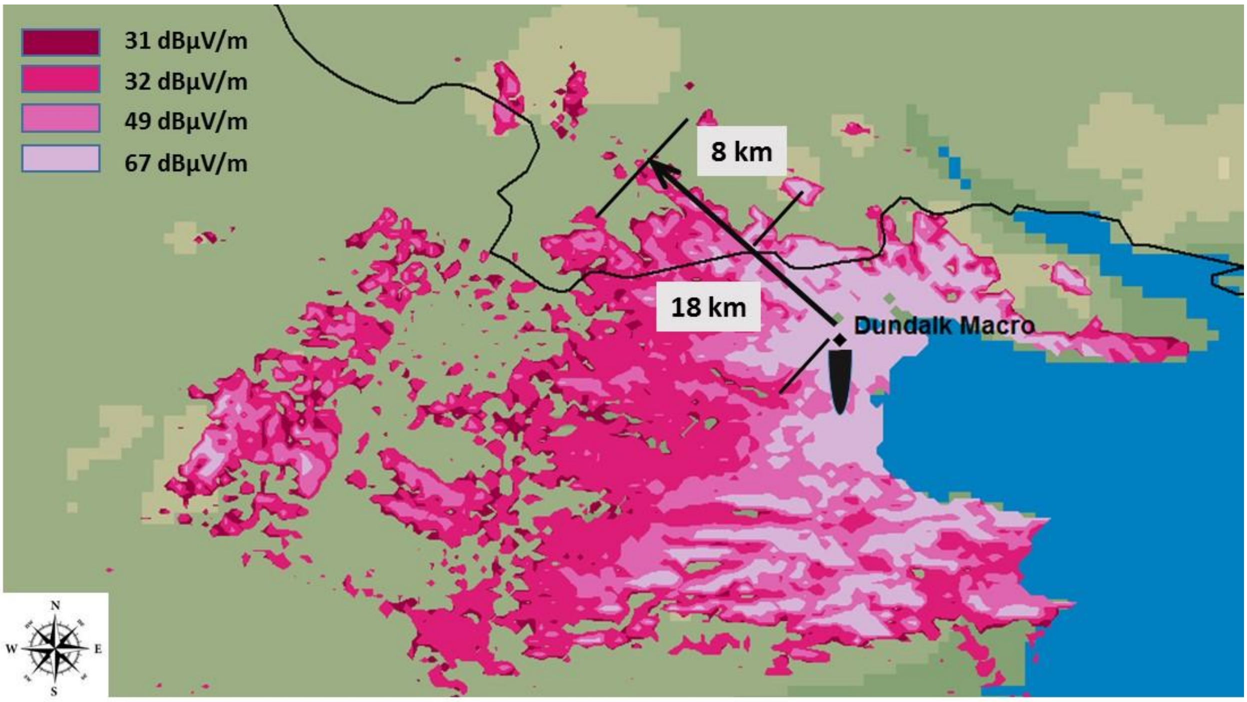
Example scenario 1: Urban macro base station

It is assumed that a south-pointing macro transmitter sector antenna is placed in central Dundalk on a mast 30 m above ground level.

Figure 5-18: Dundalk Macro Scenario (Source: Google Earth)

Cross-border interference contours are shown in the following figure.

Figure 5-19: Cross-border interference contours when an interfering macro base station pointing south is located in Dundalk (with terrain)

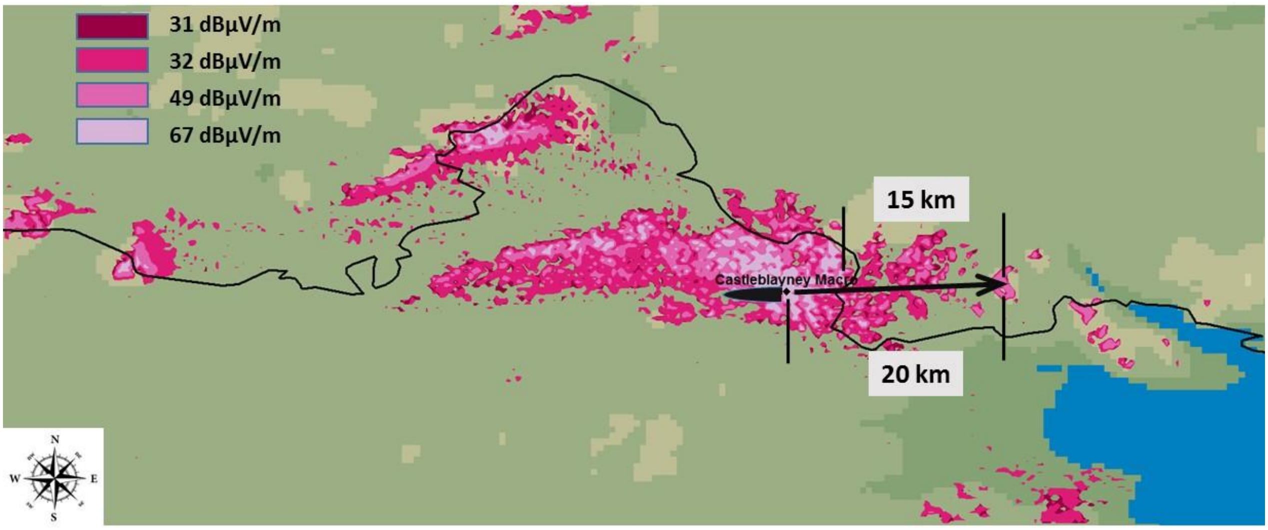


Interference through the rear of the macro base station sector antenna results in an interference area less than 8 km from the border in most directions. The distance from the transmitter is less than 18 km for the 31 & 32 dBμV/m/5MHz contours in most directions.

Example scenario 2: Elevated macro base station

This scenario considers the impact of cross-border interference from a macro base station located at a relatively high ground (115 m above sea level) in Castleblayney centre where there are existing GSM/UMTS base stations. It is assumed that the sector antenna is pointing west and placed at 30 m mast.

Figure 5-20: Cross-border interference contours when an interfering macro base station is located in Castleblayney



The areas affected across the border remain within less than 15 km in most directions when the interference paths originate from the back of the transmitter antenna. The 31 & 32 dBµV/m/5MHz contours from the back of the transmitter antenna remain below 20 km from the transmitter location in most directions.

6 Summary, Conclusions and Recommendations

We would propose that a ***co-channel coordination threshold level of 32 dBuV/m/5 MHz for 90% of the time and 90% of the locations at regional borders*** is adopted. This is to be in line with:

- typical receiver equipment characteristics that might be deployed in the band,
- an assumed conservative protection level of "6 *dB below the victim receiver noise floor"* (which is used in ECC Report 203 and implies 1 dB loss in victim link fade margin due to interference),
- percentage of time and location assumptions adopted for cross-border agreements,
- calculated required separation distances to the regional border in example scenarios analysed in this study, and
- the stringent cross-border threshold level specified in ECC Recommendation (15)01.

The height associated with this level can be 10 m when networks on either side of the border are unsynchronised (i.e. the dominant interference path is into a base station receiver) and 3 m when they are synchronised (i.e. the dominant interference path is into a user terminal receiver).

It is worth noting that if a more relaxed criterion is chosen the overall area affected by interference is reduced in some of the example cases but there are typically still a few directions where the relaxed criterion does not have a significant impact.

It is also worth noting that the operators can negotiate a less stringent criterion among themselves.

The following sections discuss the basis of the recommended co-channel coordination threshold.

6.1 Interference between Base Stations

When unsynchronised TDD networks are deployed on either side of a regional border there is the potential for base station to base station interference. In this report, the implications of base station to base station interference have been examined by considering transmitter and receiver characteristics of different types of base station (e.g. macro, micro, pico and femto).

Using the assumed modelling parameters (which are largely based on parameter values given in ECC Report 203 and information provided by ComReg on networks currently occupying the band) coordination thresholds in the form of maximum allowed field strength levels have been calculated for various types of base station receiver. On the basis of the calculated coordination thresholds, a generic interference criterion of "*field strength thresholds in the range 30 – 60 dBµV/m/5MHz to be satisfied for 90% of time and 90% locations at 10 m height*" has been assumed to accommodate potential receiver deployments.

The implications of assumed coordination thresholds have been examined by developing example interference scenarios in different parts of Ireland. Interference scenarios have been simulated by taking account of terrain features. The results have been presented in the form of an area where a given field strength threshold is exceeded, i.e. an area where there is a potential for interference.

The modelled macro base station in an urban deployment scenario gives rise to an interference area limited to approximately 30 km from the transmitter location for the most stringent criterion (i.e. 30 dBµV/m/5MHz). This is reduced to 15 km for micro base station transmitter and 10 km for pico base station transmitter. In a typical rural scenario where a macro base station is placed at a hilltop, the area of interference can extend up to 60 km from the transmitter location. These distances could be further reduced through the use of mitigation measures.

A number of mitigation measures can be deployed to ease the coordination threshold requirements. Achievable benefits are very much scenario dependent. Potential mitigation measures for base station to base station interference include the following.

- Antenna shielding to increase the interference path loss (for example, 20 dB shielding can reduce 33 km calculated in urban macro base station deployment scenario to 13 km),
- Antenna pointing away from the regional borders (for example, the urban macro base station distance is reduced from 33 km in the antenna main beam direction and 12 km in the antenna back lobe direction; similarly, in cross border scenarios, calculated distances from the border are approximately 10 km when antennas point away from the border),
- Antenna height reduction to increase the interference path propagation loss (for example, a third reduction in calculated distance in certain directions is achieved when the antenna height is reduced from 30 m to 10 m),
- Transmitter power reduction to decrease the interference power (for example, when a macro base station EIRP is reduced from 60 dBm/5MHz to 40 dBm/5MHz the limit of the interference area in most directions reduces from 33 km to 13 km),
- Antenna downtilting to enable additional antenna discrimination on the interference path (for example, an additional discrimination of approximately 5 dB is obtained when a macro base station antenna is downtilted by 6 degrees),
- The use of directional / smart antennas to reduce the spillage over neighbouring areas,
- Heterogeneous networks deploying micro / pico base stations near the regional borders,
- Antenna polarisation in fixed deployment scenarios,
- Synchronising networks on either side of the regional border to eliminate base station to base station interference paths,
- The use of preferential channels on either side of the regional border to eliminate co-channel interference scenarios.

6.2 Co-channel Interference between Base Stations and User Terminals

When synchronised TDD and/or FDD networks are deployed on either side of a regional border co-channel interference between base stations and user terminals determines the coordination threshold requirements.

Potential coordination threshold levels have been derived using representative fixed and mobile user terminal receiver modelling parameters. To accommodate a range of deployment scenarios, generic interference criteria based on "*field strength thresholds in the range 30 – 65 dBμV/m/5MHz to be satisfied for 90% of time and 90% locations at 3 m height*" have been assumed on the basis of the calculated thresholds.

Example interference scenarios have been considered to assess the impact of assumed generic interference criteria. The results show that the coordination threshold requirements for base station to user terminal interference are more stringent than those calculated for user terminal to base station interference. For example, in a typical urban deployment scenario, the area of interference extends to approximately 30 km from a macro base station transmitter and 15 km from a user terminal transmitter for the most stringent criterion (i.e. 30 dBµV/m). Similarly, in a typical rural deployment scenario, the interference area extends up to approximately 50 km from an elevated base station transmitter and 30 km from a user terminal transmitter.

Mitigation measures identified in the preceding section also apply to base station to user terminal interference paths. One of the key factors is the additional clutter loss that might be applicable in many scenarios involving user terminal receivers. For example, an additional 20 dB clutter loss can reduce the limit of the interference area from 32 km to approximately 10 km in most directions for an urban macro base station transmitter. This is demonstrated in Figure 5-11 by comparing the 30 and 50 dBµV/m/5MHz contours.

Furthermore, the user terminal transmit power control or directional antennas, in the case of fixed wireless access, might be beneficial in scenarios where the user terminal is located near the regional border.

6.3 Interference between User Terminals

User terminal to user terminal interference paths can occur when unsynchronised TDD networks are deployed co-channel in adjacent geographic areas. Coordination threshold requirements of co-channel unsynchronised TDD networks will be determined by base station to base station interference paths and these requirements will minimise the interference potential between user terminals.

6.4 Cross-border Interference

The current MoU between Ireland and the UK specifies an interference field strength level to be satisfied at a distance of 15 km from the border. There is also ECC Recommendation (15) 01 defining three coordination thresholds to accommodate different deployment scenarios involving TDD and FDD networks operating in preferential and non-preferential frequency blocks. The aim of the analysis was therefore to examine the impact of these thresholds to identify any potential deployment constraints (e.g. minimum distance to the border).

Analysis with terrain, using example sites near Northern Ireland, has shown that thresholds are most likely to be exceeded over a limited area near the border, e.g. within 10 km. The noticeable exception, is hilly areas, which can extend the areas affected to 20 – 25 km from the border but it is likely that many of these are not populated.

A worst case scenario, where it is assumed that the Three Rock site (450 m above sea level) near Dublin is used to deploy a macro base station, could result in sea path interference affecting mainly hilly areas up to 25 km from the Welsh coastline where the 31 & 32 dBµV/m/5MHz threshold levels can be exceeded.

7 Glossary

ACLR	Adjacent Channel leakage Ratio
AMC	Adaptive modulation and coding
CPE	Customer Premises Equipment
CQI	Channel Quality Indicator
BEM	Block Edge Mask
BS	Base station
BWA	Broadband Wireless Access
CC	Component Carriers
CEPT	European Conference of Postal and Telecommunications Administrations
CoMP	Coordinated Multipoint
DAE	Digital Agenda for Europe
DL	Downlink
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
EC	European Commission
ECC	Electronic Communications Committee
ECC PT1	Electronic Communications Committee Project Team 1
ECC WG FM	Electronic Communications Committee Working Group Frequency Management
ECP	European Common Proposal
ECS	Electronic Communication Systems)
eiCIC	Enhanced inter-cell interference coordination
EIRP	Effective Isotropic Radiated Power
eMBMS	Evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B (LTE Base Station)

ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FFS	For Further Study
FWA	Fixed Wireless Access
FWALA	Fixed Wireless Access Local Area
FTTC	Fibre to the cabinet
Gbps	Gigabits per second
GNSS	Global Navigation Satellite System
HeNB	Home evolved Node B (LTE Femtocell)
HetNet	Heterogeneous network (supports interaction between different types of cells and technologies)
HFC	Hybrid Fibre Coaxial (cable broadband technology)
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IMT-A	International Mobile Telecommunications Advanced (4th generation mobile)
IMT-2000	International Mobile Telecommunications (ITU 3rd generation mobile standard)
IP	Internet Protocol
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union - Radiocommunications
I/N	Interference to Noise Ratio
LTE	Long Term Evolution (4th generation mobile technology standard)
LTE-A	LTE Advanced (latest version of the LTE standard)
LTE-LAA	Licensed Assisted Access LTE (version of the LTE standard)

LTE-U	Unlicensed LTE (version of the LTE standard)
Mbps	Megabits per second
MCL	Minimum Coupling Loss
MIMO	Multiple Input Multiple Output
MFCN	Mobile Fixed Communications Networks
MoU	Memorandum of Understanding
NGA	Next Generation Access
NTIA	US National Telecommunications and Information Administration
OECD	Organisation for Economic Co-operation and Development
OFDMA	Orthogonal Frequency Division Multiple Access
PCI	Physical Layer Cell Identities
PSSR	Public Sector Spectrum Release (process for spectrum award in UK)
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RF	Radio Frequency
RRC	Radio Resource Control
SCFDMA	Single Carrier Frequency Division Multiple Access
SCH	Shared channel
SDL	Supplemental downlink
SRTM	Shuttle Radar Topography Mission
TDD	Time Division Duplex
TD-LTE	Time Division- Long Term Evolution
TD-SCDMA	Time Division – Synchronous Code Division Multiple Access
TTI	Transmission Time Interval
UE	User equipment

UL	Uplink
UT	User terminal
UTC	Coordinated Universal Time
VDSL	Very high speed digital subscriber line
WRC	World Radio Conference
WRC-15	World Radio Conference 2015
WiMAX	Wireless Microwave Access (wireless broadband technology)
3D	3 Dimensional
3GPP	3rd Generation Partnership Project (body responsible for LTE-A standards)

Appendix A: ECC Report 203 - BEM Calculation Approach

The approach adopted to derive base station block edge masks in ECC Report 203 is summarised below.

- LTE, WiMAX and other multi-standard radio specifications are used to derive transmitter, receiver and deployment parameters for the modelling. Macro, micro, pico and femto cell base stations, as well as generic user equipment parameter values are provided.
- Minimum coupling loss (MCL) calculations are implemented, for the base station to base station interference analysis (for FDD uplink and unsynchronised TDD deployments). These calculations assume a given horizontal distance, between two base stations of different networks. For example, macro to macro base station separation of 70 m and femto to femto base station separation of 10 m are assumed. It is also assumed that out-of-band emissions are more significant than the receiver selectivity. Using in-band EIRP, ACLR and an interference threshold of I/N of -6 dB, the maximum allowed out-of-block EIRP from an interfering transmitter is determined for each combination of macro, micro, pico and femto base stations. For example, the macro to macro base station scenario allows an interfering transmitter EIRP of -35 dBm/5MHz while femto to femto base station scenario allows an interfering transmitter EIRP of -26.5 dBm/5MHz.
- MCL calculations are followed by simulation analysis. Simulation results are presented in the form of throughput degradation. Average (where throughput reduction is averaged over all users) and 5% (where throughput reduction is calculated for users with the worst, i.e. the least, throughput) degradation metrics are used. For example, 100% throughput reduction for both metrics is calculated with no additional isolation. This is decreased to 5.5% for average degradation and 2.7% for 5% degradation when an additional isolation (e.g. additional filtering) of 37 dB is introduced.
- Monte Carlo simulations are undertaken to examine interference from base stations into user terminals for indoor/outdoor and macro/micro/pico/femto scenarios. The average and 5% throughput degradation metrics are also used to quantify the interference impact. In many cases, the average throughput degradation remains below 1%. The report then argues that, as the degradation results (calculated using ACLR levels given in standards) are sufficiently low, the base station ACLR together with emission masks (based on multi-standard radio specification) can be used to determine block edge mask requirements. These are subsequently which are calculated by a manipulation of the ACLR and spectrum emission masks to accommodate for different interferer and victim bandwidths.
- The base station to base station and base station to user terminal analysis results are then combined to derive base station BEMs. The base station BEM includes in-block power limit and out-of-block transitional and baseline levels.
- The report provides a set of EIRP limits for the base station block edge mask elements for FDD, synchronised and unsynchronised TDD co-existence among macro, micro, pico and femto base stations, with additional limits specified to protect military radars. To enable co-existence among unsynchronised TDD base stations, proposed solutions include a frequency separation (i.e. guard band) between the edges of the two adjacent operators, the use of restricted blocks where EIRP is lower than the in-block limit in the upper and lower part of the contiguous blocks assigned to an operator and the use of internal guard bands agreed by the adjacent operators.

Appendix B: SEAMCAT Base Station and Base Station Interference Modelling

B.1 Baseline Calculations

Table B-1 below provides pessimistic minimum distance requirements for macro (assumed to be pointing towards the reference point where the threshold is defined), micro, pico and femto base station transmitters based on SEAMCAT Rec.452 implementation, where terrain effects are not considered. It is worth noting that the impact of macro and micro base station elevation patterns are taken into consideration when calculating required distances.

Table B-1: Minimum distance to regional border at which assumed coordination threshold is satisfied (no terrain)

	Coordination threshold (dBµV/m/5MHz) (to be satisfied @ 10m for 90% of time and 90% of locations)			
Interfering BS Transmitter	30	40	50	60
Macro	73 km	60 km	49 km	38 km
Elevated Macro	94 km	83 km	67 km	57 km
Micro	34 km	24 km	17 km	10.5 km
Pico (Indoor)	10.5 km	6 km	2.5 km	< 1 km
Femto (Indoor)	6 km	3 km	1.5 km	< 1 km

For the deployment scenarios where there is the possibility of interference between base stations of different operators (e.g. unsynchronised TDD networks), results show that the worst case corresponds to the scenario where an interference path originates from an elevated macro base station and the interference field strength level is 30 dBµV/m/5MHz. This scenario requires 94 km separation from the regional border.

B.2 Macro Base Station Antenna Pointing Sensitivity

The following table compares the separation distances obtained by assuming that the interfering macro base station is pointing towards and away from the reference point where a coordination threshold level of 30 dBµV/m/5MHz needs to be satisfied. The results indicate that the use of spectrum can be optimised by deploying base stations near regional borders pointing away from the neighbouring victim base station receivers.

Table B-2: The impact of macro base station antenna pointing (no terrain)

Scenario	Minimum required distance to satisfy coordination threshold of 30 dBμV/m/5MHz
Interfering station pointing towards victim	73 km
Interfering station pointing away from victim	51 km

B.3 Macro Base Station EIRP Sensitivity

The following table compares the separation distances obtained by assuming that the interfering macro base station EIRP is 60 dBm/5MHz and 68 dBm/5MHz which is the non-obligatory upper limit given in EC Decision 2014/276/EU.

Table B-3: The impact of macro base station EIRP (no terrain)

Scenario	Minimum required distance to satisfy coordination threshold of 30 dBμV/m/5MHz
60 dBm/5MHz	73 km
68 dBm/5MHz	96 km

Appendix C: SEAMCAT Base Station and User Terminal Interference Modelling

C.1 Base Station to User Terminal Interference Baseline Calculations

The following table provides pessimistic minimum separation distances calculated by assuming that no terrain effects apply between an interfering base station transmitter and a reference point where a given level of field strength level needs to be satisfied.

Table C-1: Minimum distance to regional border at which assumed coordination threshold is satisfied (no terrain)

	Coordination threshold (dBµV/m/5MHz) (to be satisfied @ 3m for 90% of time and 90% of locations)				
Interfering BS Transmitter	30	40	50	60	65
Macro	69 km	55 km	44 km	32 km	28 km
Elevated Macro	89 km	77 km	65 km	49 km	43 km
Micro	29 km	18 km	12 km	6.5 km	4.5 km
Pico (Indoor)	7 km	3.5 km	1.8 km	< 1 km	< 1 km
Femto (Indoor)	3.9 km	1.7 km	< 1 km	< 1 km	< 1 km

For the assumed user terminal receiver coordination thresholds (referenced to an assumed 3 m height), the largest separation distance is 89 km corresponding to an elevated macro base station transmitter and 30 dBµV/m/5MHz coordination threshold. For the micro, pico and femto base station interferer scenarios, separation distances remain below 30 km.

C.2 User Terminal to Base Station Interference Baseline Calculations

The impact of interference from fixed and mobile user terminal transmitters has been examined for the base station receiver coordination threshold range of 30 – 60 dBµV/m/5MHz. The pessimistic separation distances calculated with no terrain are shown in the following table.

Table C-2: Minimum distance to regional border at which assumed coordination threshold is satisfied (no terrain)

		Coordination threshold (dBµV/m/5MHz) (to be satisfied @ 10m for 90% of time and 90% of locations)			
Interfering UT Transmitter		30	40	50	60
Fixed	Pointing Towards BS RX	19 km	11.5 km	6.5 km	3 km
	Pointing Away from BS RX	5 km	1.7 km	< 1 km	< 1 km
Mobile		17.5 km	9.5 km	4.8 km	2.6 km

Compared to the base station to user terminal separation distances, the coordination threshold requirements for user terminal to base station interference are less stringent leading to few kilometre separation distances in most scenarios.

Appendix D: SEAMCAT Cross-Border Interference Modelling

For each cross-border threshold level, the following pessimistic minimum distance requirements have been calculated using SEAMCAT's generic Rec.452 implementation where terrain effects are not considered.

Table D-1: Minimum distance at which cross-border coordination threshold is satisfied (no terrain)

		Coordination threshold (dBμV/m/5MHz)			
Interfering BS Transmitter		31 (10 m height 15 km from the border)	32 (3 m height at the border)	49 (3 m height 6 km from the border)	67 (3 m height at the border)
		to be satisfied for 90% of time and 50% of locations	to be satisfied for 90% of time and 90% of locations		
Macro	Pointing towards border	63 km	67 km	45 km	27 km
	Pointing away from border	43 km	44 km	27 km	13 km
Elevated Macro	Pointing towards border	85 km	87 km	66 km	41 km
	Pointing away from border	74 km	74 km	50 km	15 km
Micro		25 km	28 km	12.5 km	4.2 km
Pico (Indoor)		6.7 km	6.7 km	2 km	< 1 km
Femto (Indoor)		3.3 km	3.3 km	< 1 km	< 1 km

Calculated distances suggest that:

- The threshold level specified in the current MoU between the UK and Ireland requires 10, 48 and 70 km distances to the border for micro, macro and elevated macro base station transmitters respectively. If the macro and elevated macro base stations point away from the border the distance requirements are 28 and 59 km respectively.
- The 32 dBμV/m/5MHz threshold (defined for unsynchronised TDD networks, systems operating in non-preferential blocks and FDD systems interfering with TDD networks) requires 3.3 – 87 km

distance to the border depending on the type of interfering base station deployed. The micro, macro and elevated macro base stations require 28, 67 and 87 km separation distance from the border respectively. These are more stringent than the distances calculated for the current MoU level. The required distances to border are 44 and 74 km if the macro and elevated macro base stations are pointing in the opposite direction with respect to the border.

- The 49 and 67 dBµV/m/5MHz thresholds (defined for synchronised TDD networks, systems operating in preferential blocks and FDD networks interfering with FDD networks) require distances of up to 60 km to the border depending on the type of interfering base station considered. The requirements for the micro, macro and elevated macro base stations are 6.5, 39 and 60 km respectively, which are less stringent than those calculated for the current MoU level. In scenarios where the macro and elevated macro base stations are pointing away from the border the separation requirement is 21 km for the macro base station and 44 km for the elevated macro base station.

Appendix E: Cross-Border Interference Modelling With Terrain

The following are further examples of cross-border interference scenarios.

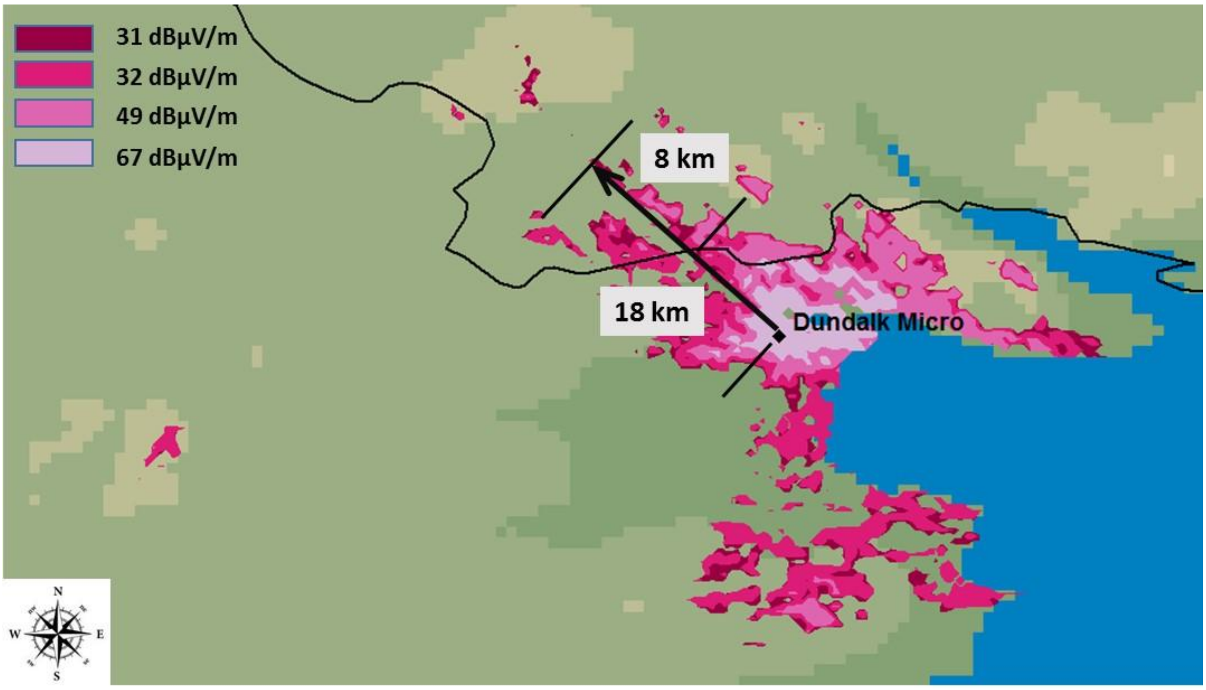
E.1 Micro base station transmitter

A micro base station with horizontal omnidirectional pattern is assumed to be located in central Dundalk near the railway station (where there are existing GSM/UMTS base station transmitters) at 6 m height above ground level.

Figure E-1: Dundalk Micro Scenario (Source: Google Earth)

Simulation results are plotted in the figure below.

Figure E-2: Cross-border interference contours when an interfering micro base station is located in Dundalk

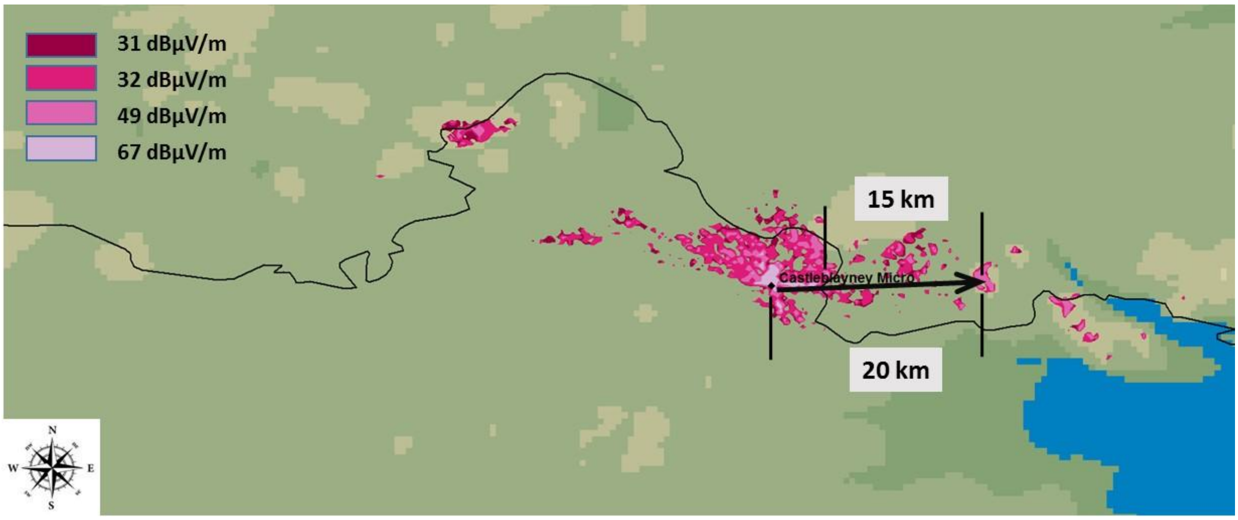


Compared to the macro base station case (presented in the main body of the report) where interference across the border was through the back of the macro base station antenna, the micro base station antenna with omnidirectional horizontal pattern results in a reduced interference area across the border though the extent of the interference area is still limited by 8 km for most directions. The 31 & 32 dBµV/m/5MHz contours from the transmitter remain below 18 km in most directions.

E.2 Elevated micro base station transmitter

A micro base station with omnidirectional horizontal antenna is assumed to be transmitting in Castleblayney.

Figure E-3: Cross-border interference contours when an interfering micro base station is located in Castleblayney

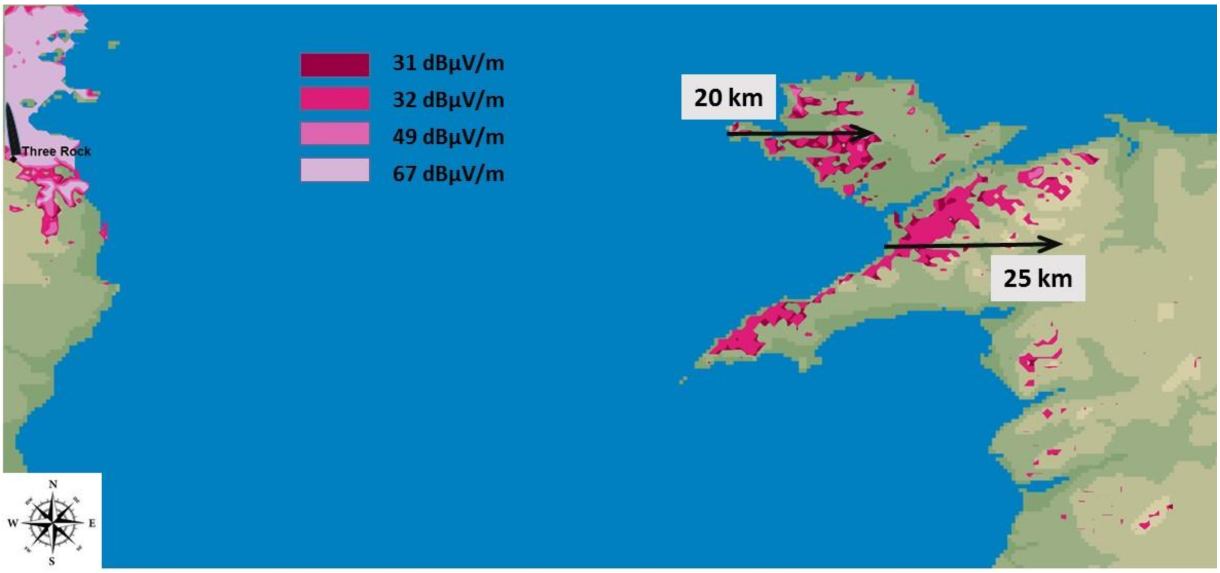


As can be seen, areas affected are not large but the high ground (550 m above sea level) located 15 km from the border remains within the 31, 32 & 49 dBµV/m/5MHz interference contours.

E.3 Sea path interference from hilltop macro base station

The final cross-border example considers sea path interference into the UK from a hilltop transmitter located at Three Rock (450 m above sea level). It is assumed that the transmitter antenna is pointing at North West towards Dublin centre.

Figure E-4: Sea path cross-border interference from Three Rock



Although interference area extends to 20 – 25 km from the shore due to hills nearby most areas affected remain within 10 km of the coast line.

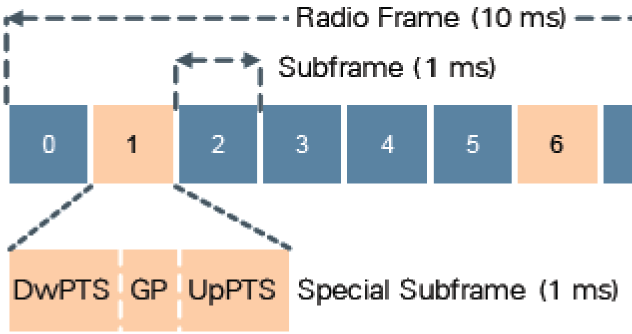
Appendix F: Synchronisation

F.1 Introduction

Time Division Duplex (TDD) divides a data stream into frames and assigns different time slots to uplink and downlink transmissions and so allows the spectrum to be shared in both directions of transmission.

F.2 Frame structure of TDD

As noted above in the case of TD-LTE it can change the number of time slots allocated to the UL and DL to take account of the different traffic requirements although typically require greater capacity in the DL (Base station to user terminal). To support this switching between UL and DL there is a special sub frame as shown in the figure below: Figure F-1: TDD Frame Structure (Source: Motorola White Paper)



Each radio frame consists of ten 1ms sub frames and the special sub frames (sub frames 1 and 6 in the figure above) serve as the switching point between DL and UL. It is possible to have a single switching point assuming a 10ms periodicity or two switching points (sub frames 1 and 6) for a 5 ms periodicity. Depending on which switching points are used a range of different DL / UL allocations can be supported as shown in the table below:

Table F-1: DL / UL configurations supported by TD-LTE

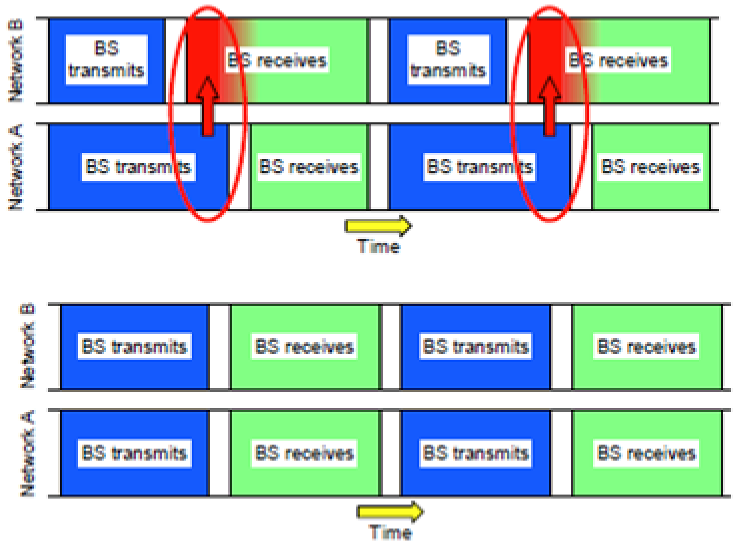
DL / UL Configuration	Period (mS)	Sub frame									
		0	1	2	3	4	5	6	7	8	9
0 (1:3)	5	D	S	U	U	U	D	S	U	U	U
1 (1:1)		D	S	U	U	D	D	S	U	U	D
2 (3:1)		D	S	U	D	D	D	S	U	D	D
3 (2:1)	10	D	S	U	U	U	D	D	D	D	D
4 (7:2)		D	S	U	U	D	D	D	D	D	D
5 (8:1)		D	S	U	D	D	D	D	D	D	D
6 (3:5)	5	D	S	U	U	U	D	S	U	U	D

The length of each field within the special sub frame may vary depending on the TDD system (e.g. LTE, WiMAX etc.) providing they do not exceed to total period of 1ms.

F.3 Potential for interference

The figure below illustrates the potential for interference when the uplink and downlink are not aligned for networks operating either side of the regional border. When the uplink and downlink ratios used by the network operators are the same then any interference will be between base stations and user terminals.

Figure F-2: Interference scenario for TDD to TDD networks (Source: Early draft of ECC Report 216)



In ECC Report 216[20] it notes that to achieve synchronised operation in LTE TDD networks (both within the operator' network and between other operators in the same frequency band), each base station that might interfere with others must have the following implemented:

- **Common reference phase clock** (e.g. for the start of frame). TDD needs a common phase reference and the desired accuracy depends on the technology. The order of magnitude for currently considered IMT technologies is about 1 to 3µs of clock drift between base stations. In practical deployments UTC is mostly used as a common time reference.
- **Configuring compatible frame structures** (e.g. length of frame, TDD ratio, etc.) in order to align uplink/downlink switching points. This is straightforward in the case of the same technology, but it needs careful analysis in the case of cross-technology synchronisation. In the case of WiMAX/LTE-TDD synchronisation, it is straightforward in most cases even though

[20] See ECC Report on "Practical Guidelines for TDD networks synchronisation", April 2014.

specific cases need more work. ECC Report 216 considers a range of different technologies and cell deployments.

In the following sections we provide more detail on what is meant by synchronised operation in this instance, possible techniques to provide the reference source and considerations for operator cross-border agreements.

F.4 Frame structure for synchronised operation

The radio frame structure (frame length and DL / UL ratio) may be configured through software parameters. However there is the possibility of different DL / UL ratios being used in neighbouring networks and synchronising the start of the frame is not sufficient to avoid the potential for interference between two base stations being deployed co-channel or adjacent channel. This is because there is the possibility that in the two different networks they will transmit in one network and receive in the other at the same time leading to interference between base stations which is the worst case interference scenario.

Synchronised operation between two networks can mean that "no simultaneous uplink and downlink occurs between any pairs of cells" and this requires them to be synchronised in phase. This requires a common phase reference, mentioned in the next section, and also compatible frame structures to ensure that the "last transmitter stops before the first receiver starts taking into account propagation delay" for where there may be line of sight between base stations.

This means operators will need to agree a common frame structure – the frame length and downlink to uplink ratio. The TDD ratio can be set at any value (see above figure) and changed by mutual agreement at any time as it is set through software. The disadvantage of this approach is it removes the opportunity for operators to set up their networks to match their specific network requirements but it should increase spectrum efficiency by minimising the potential for interference and requirement for additional guard bands.

This approach is relatively straightforward where the technologies deployed by the base stations are the same but when the technologies are different (e.g. TD-LTE and WiMAX) then it is necessary to undertake a case-by-case analysis. This is expanded on in ECC Report 216, section 2.3.2 and Annex 1, where it is identified that "most WiMAX 802.16e configurations have at least one equivalent TD-LTE set of parameters". Based on currently available technologies[21] the two applicable LTE configurations for co-existence with WiMAX, depending on the applicable WiMAX configuration(s), are 1 and 2[22].

The WiMAX and LTE-TDD frame structures are described in Annex 1 of ECC Report 216.

F.5 Reference phase clock

To achieve synchronisation a suitable reference phase / time clock is required. .ECC Report 216 provides a comparison of the available options and their applicability to different network deployments (for example some technologies may only be suitable for macro cells). The table below provides an overview:

[21] It is noted that WiMAX Forum profiles only support 5ms frame length and TDD ratios above 50% for the down-link

[22] See Table F-1: LTE configurations 1 and 2 are based on DL/UL ratios of 1:1 and 3:1 respectively.

Table F-2: Summary of assessed techniques for various scenarios (Source: ECC Report 216)

	GNSS	Packet networks	LTE OTA (1)	eLoran
Status	Mature. Implemented in existing outdoor TDD networks (e.g. WiMAX & TD-SCDMA). May experience some outages due to lack of visibility of satellite. Some GNSS system are not yet fully available (e.g. Galileo)	G.8275.1 assumes full on-path timing support (i.e. all equipment between GM and slave must have dedicated hardware and software support for IEEE-1588v2). Expected in 2014. G.8275.2 will address assisted partial on-path timing support case (PTPv2 used to backup GNSS failure). Under specification. G.8275.x: partial on-path timing support. Not yet defined	Available for HeNB. Under study for other type of cells and scenarios	Essentially used in maritime navigation and military contexts, but not yet used for IMT
Cross-technology (e.g. WiMAX-LTE)	Yes	Yes	No, LTE-only	Yes
Works indoors	Generally not, although some improvements in chipset performance may make this applicable on a case-by-case basis. Subject to intentional or unintentional outages from time to time so requires some form of back-up.	N/A (not based on RF technologies. Applicability depends on network characteristics). Work and tests are still ongoing on indoor small cells scenarios	Yes, up to 3 HeNB-to-HeNB hops. Work-item ongoing for more hops and for more deployment scenarios	FFS. The signal is expected to have good indoor penetration. However this has not yet been tested with low-cost low-footprint chipsets and antennas (which also require further studies)

(1) **Over-the-air synchronisation**: 3GPP has defined a mechanism that allows a slave cell to get the phase clock from a master cell.

F.6 Operator agreements

The following is a list of agreements that must be made between operators when deploying synchronised TDD networks[23].

- A common phase clock reference (e.g. UTC) and accuracy/performance constraints (e.g. +/- 1.5μs), either using their own equipment to provide the clock, or sharing the same phase/time clock infrastructure;
- A compatible frame structure (including TDD UL/DL ratio) in order to avoid uplink/downlink overlapping;
- A commitment not to interfere with each other as any synchronisation issue of one operator may impact the network of the others (e.g. reliability of the reference clock and protection mechanism have to be ensured and/or procedure when losing this reference clock has to be defined);
- The terms & conditions where cross-operator synchronisation must apply and/or may not be required (e.g. geographical zones / isolated eNB and HeNB-only deployments);
- How to update those parameters.

When multiple operators deploy TDD networks on adjacent bands or the same band inter-network synchronisation conditions can be discussed and agreed at the national level and implemented nationwide or limited to a given area (regional) as appropriate.

[23] CEPT ECC Report 216