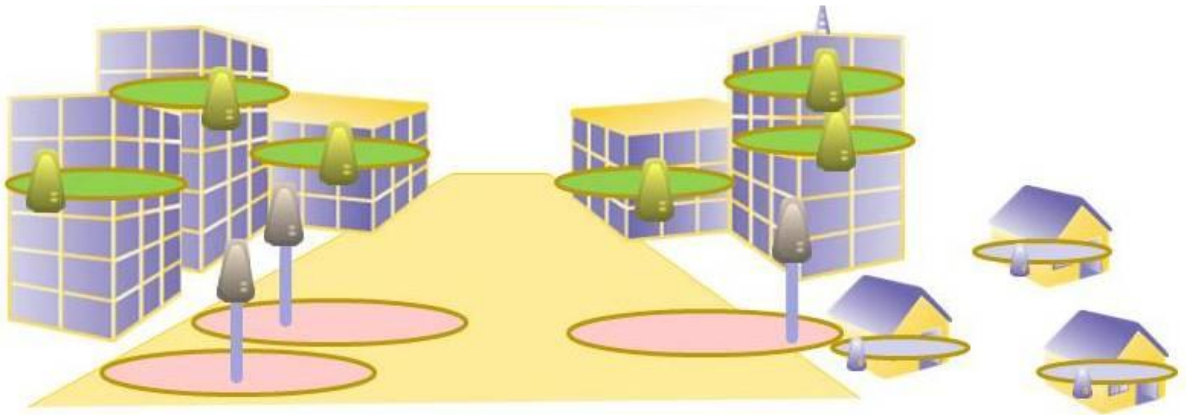
Final Report

Studies in Support of Technical Licence Conditions for the 2.6 GHz Frequency Band

On behalf of Ofcom



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About Real Wireless

Real Wireless is a leading independent wireless consultancy, based in the U.K. and working internationally for enterprises, vendors, operators and regulators – indeed any organization which is serious about getting the best from wireless to the benefit of their business. We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process. We are experts in radio propagation, international spectrum regulation, wireless infrastructures, and much more besides. We have experience working at senior levels in vendors, operators, regulators and academia.

We have specific experience in LTE, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA – and many more.

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1 Executive Summary

1.1 Background

1.1 This report provides technical analysis in support of the Ofcom's consultation relating to the technical licence conditions applicable to the forthcoming award of the 2.6 GHz spectrum band (2500 – 2690 MHz).

1.2 The analysis relates to a specific set of issues identified by Ofcom as having the potential to cause interference both amongst licensees within the band and to adjacent services.

1.2 Scope of study

1.3 This study relates to potential interference issues amongst several particular services likely to make use of the 2.6 GHz band:

1.3.1 Time Division Duplex (TDD) services in the 2570-2620 MHz unpaired block, especially those which use the restricted block from 2570-2575 MHz, which may interfere with adjacent Frequency Division Duplex (FDD) base station receivers. In line with a European Commission Decision, Ofcom needs to set appropriate restrictions on the TDD systems.

1.3.2 Low power FDD access points (femtocells, picocells, microcells) which meet 3GPP specifications but could nevertheless create interference into nearby radar receivers operating above 2700 MHz. Ofcom needed a view on the impact of assigning spectrum for access points in terms of avoiding such interference while minimising access point design changes which would be UK-specific.

1.3.3 Low power and standard power FDD operators who in some circumstances could share a portion of the paired spectrum on a hybrid basis. Ofcom wish to determine whether technical licence conditions could be applied to limit the extent of interference to standard power licensees.

1.3.4 Multiple low power licensees who may operate low power FDD services on a concurrent basis and may create interference to each other when deploying in a common geographical area. Ofcom wish to determine whether any limits exist on the maximum number of licensees who could share spectrum in this way, whether in hybrid mode with a standard power licensee or in a dedicated block of spectrum.

1.4 Our study addresses all of these issues and provides recommendations for Ofcom to consider in setting the relevant technical licence conditions.

1.3 Our approach and assumptions

1.5 Throughout this report we have adopted parameters and modelling approaches which are consistent wherever appropriate with our previous work in [3] and with Ofcom's wider technical analysis in [4].

1.6 In places where additional assumptions are required, we have used references from 3GPP and discussions with particular vendor stakeholders to inform our choices.

1.7 Although licences for this spectrum are expected to be technology neutral, Ofcom requested that systems complying with the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standards should be the basis of our analysis.

1.4 Our results

A: Protecting FDD base station receivers from TDD systems operating in the restricted block

1.8 In assessing potential interference to FDD systems receiving in 2550-2570 MHz from TDD systems operating in the restricted block of unpaired spectrum from 2570-2575 MHz, we found that a combination of restrictions of height and separation distance should be sufficient to provide adequate protection given the use of the alternative Block Edge Mask defined by the European Commission [5].

1.9 The required minimum separations are 40 m for outdoor TDD systems protecting FDD microcells and 160 m for outdoor TDD systems protecting FDD macrocells.

1.10 For indoor TDD systems, distances between 20m to protect FDD microcells and 70m to protect FDD macrocells are required.

B: Frequency placement of low-power access points

1.11 In order for low power access points to meet the European Commission (EC) restriction on emissions below 2615 MHz and additional emission limits above 2700 MHz simultaneously, we found that they should not be operated in either the top or bottom channels of the 2620 – 2690 MHz subband, as this would involve very challenging additional filtering given the limited frequency space within which the filters would need to roll off.

1.12 In order to avoid hardware changes on units which otherwise meet 3GPP specifications, or to avoid significant reductions in maximum power below the intended 30 dBm Equivalent Isotropically Radiated Power (EIRP) maximum, a limited set of channel options is available depending on the transmission bandwidth, as follows:

1.13 These recommendations assume that Ofcom licenses a maximum EIRP of 30dBm for Home and Local Area BS in UK.

1.14 Ofcom is proposing an unwanted emissions limit of -45 dBm/MHz above 2700 MHz. However, in certain circumstances it would be advantageous for unwanted emissions to be kept below this regulatory limit (e.g. to reduce the need for detailed coordination with Radar operators close to Radar sites). For this reason Ofcom has asked us to study the impact of meeting two unwanted emissions values: the proposed -45 dBm/MHz regulatory limit and a lower level of -65 dBm/MHz.

1.15 For 10MHz channels, if needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

1.16 For 10MHz channels, if needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz.

1.17 For 20MHz channels, if needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2660MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

1.18 For 20MHz channels, if needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2670MHz. This may mean the vendor requires additional RF filtering to meet this unwanted emissions level.

1.19 Using these recommended frequency ranges, the implication on access point vendors is likely to be:

- For BS using 10MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after Power Amplifier (PA) device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS
- For BS using 10MHz channels, having to meet an unwanted emissions level of -45dBm/MHz:
    - For 30 dBm EIRP, vendors can probably use an unmodified but well-designed BS
    - For 27 dBm EIRP, vendors can probably use an unmodified but well-designed BS
    - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS
- For BS using 20MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 20 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
- For BS using 20MHz channels, having to meet an unwanted emissions level of -45dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter

1.20 For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS.The results define the optimal channels as follows:

Emission Level above 2700MHz	Low power block bandwidth	Optimal channel centre frequency
-65dBm/MHz EIRP	10 MHz	2635 MHz
	20 MHz	2650 MHz
-45dBm/MHz EIRP	10 MHz	2635 to 2675 MHz
	20 MHz	2650 to 2660 MHz

Table 1 Optimal placement of the low-power block to avoid additional filtering

1.21 Even at these channel centre frequencies, in order to meet an unwanted emissions level above 2700MHz of -65dBm/MHz EIRP, it is likely that the operator would need to reduce the output power EIRP to 28dBm and 25dBm in the 10MHz and 20MHz channel bandwidth cases respectively or use a modified access point with higher selectivity output filter, in order to meet this unwanted emissions level.

1.22 At these channel centre frequencies, in order to meet the proposed regulatory limit on unwanted emissions above 2700MHz of -45dBm/MHz EIRP, it is likely that the operator could use an unmodified access point at the full 30dBm EIRP power level.

C: Hybrid shared spectrum

1.23 For the purposes of this study, standard power networks are assumed to have priority over low power networks in the shared portion of the spectrum.

1.24 We examined a range of approaches which would allow low power licensees operating in hybrid mode to determine situations in which there are significant risks of creating interference to standard power licensees in the shared block of spectrum. Several of these approaches are best facilitated by some level of information sharing between licensees, particular regarding the locations and other basic parameters of the base stations.

1.25 The low power access point and mobile terminal stations should control their transmit power within the block of spectrum shared with the standard power licensee based on measurements in order to limit interference to the standard power network to within agreed acceptable limits. Ideally they should use measurements made by both the low power access point and by nearby mobile stations, and mechanisms and messages exist within 3GPP standard to facilitate these.

1.26 Potential coordination rules to limit both downlink and uplink interference were proposed and analysed. Depending on the parameters used in these rules, the interference can be limited to essentially any desired degree, at the expense of degradation in the service available to users of the low power networks.

1.27 Where the low power systems are unable to make measurements of the standard power systems, the low power systems must not be deployed within the coverage area of a standard power base station unless they avoid use of the shared portion of the spectrum. The relevant coverage area will depend on the type of standard power base station deployed.

D: Number of low power licences

1.28 Whilst there is no fundamental limit to the overall number of licenses that can be awarded for the low power shared access, there are limits on the number of cells from different licensees that can operate with overlapping coverage. In order that multiple licensees sharing overlapping spectrum can provide services over the same geographical area, the relevant control channels should be co-ordinated such that they are not transmitted on the same time and frequency resources.

1.29 A combination of time shifting and/or carrier offsetting can be used to avoid transmission on the same resources.

1.30 Given such coordination, the overall resources available to deliver capacity reduces as the number of licensees in a given area increases. In a hybrid 2x20 MHz channel, our calculations indicated that the available resources would be reduced to below 50% for more than 5 licensees in the same area. For a dedicated 2 x 10 MHz channel the resources are degraded to below 50% for more than 6 licensees.

2 Introduction

2.1 UK spectrum at 2.6GHz is due to be auctioned shortly

2.1 Ofcom is consulting on proposals to auction licences for the frequency band 2500 MHz – 2690 MHz (the "2.6 GHz" band) together with other bands, with the award of licences expected to take place in 2012. The band is arranged as 2500 – 2570 MHz (uplink) paired with 2620 – 2690 MHz (downlink), plus an unpaired portion 2570 – 2620 MHz. Although the award will be on a technology neutral basis, the expected technologies are Long Term Evolution (LTE) in frequency division duplex mode in the paired spectrum and Worldwide Interoperability for Microwave Access (WiMAX) or Time Division (TD) -LTE in the unpaired spectrum.

2.2 The 2.6GHz band is recognised as a highly desirable band for cellular operators and vendors, as its usage has been commonly defined for International Mobile Telecommunications by the International Telecommunications Union in all three of its regions [1]. This international harmonisation of the band allows vendors and operators to benefit from greater economies of scale. Sometimes known as the Universal Mobile Telecommunications System (UMTS) expansion band, it was originally anticipated that this band would be used by cellular operators to provide additional capacity to 3rd Generation (3G) networks [1]. However, more recently it has been associated with 4th Generation (4G) networks and indeed is already being used in Sweden, Norway, Uzbekistan and Hong Kong to provide LTE services and in several places including the US to provide WiMAX services [2].

2.3 In Europe, Commission Decision 2008/477/EC outlined technical parameters, including frequency arrangements and block edge masks (BEM), for devices within this band. This band has already been auctioned in many European countries including Denmark, Finland, Germany, Norway, the Netherlands and Sweden [1].

2.4 In a previous study, Real Wireless examined the potential to use a portion of the 2.6 GHz band for shared low power use [3]. Ofcom subsequently published proposals [4] for making this spectrum available and included a discussion of options for low-power use, which took account of the technical analysis in that report . At this time, Ofcom indicated that it would be publishing further consultations in support of the award. The present document details a study in support of a further consultation on the technical licence conditions relevant to the 2.6 GHz band.

2.5 In particular, the study examines interference issues amongst services which are likely to share the 2.6 GHz band and those which are in adjacent bands.

2.2 Several distinct uses of 2.6 GHz and nearby bands could lead to interference challenges

2.6 An overview of the band-plan for the 2.6 GHz band is shown in Figure 1.The 2.6 GHz band extends between 2500 MHz and 2690 MHz, organised into 2 x 70 MHz of paired spectrum with 120 MHz duplex spacing for FDD services and a central 50 MHz unpaired block for TDD services. Within the paired spectrum, Ofcom is consulting on having two types of licences, one type with *standard power* conditions for use by one operator and another type with technical conditions suitable for *low power* networks sharing access to a block of spectrum. If licensing of low-power networks is implemented in the spectrum award, the potential approaches are to dedicate a spectrum block to low-power while the other blocks in the band are dedicated for standard power, or to follow a hybrid approach. Under a hybrid approach, one standard power licence includes some dedicated spectrum and some shared with low-power licensees; low-power licences also include some dedicated spectrum and some shared with the standard power licensee. Radar services occupy frequencies starting at 2.7 GHz.

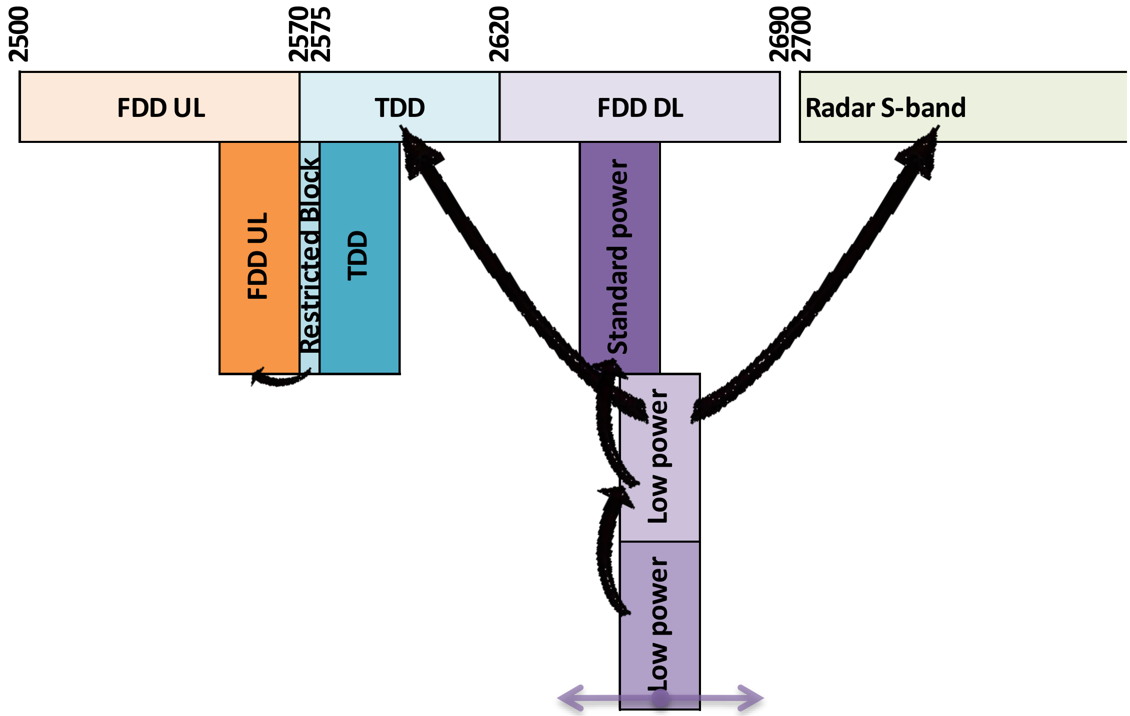

Figure 1: Overview of bandplan for 2.6GHz, showing some potential interference modes

2.7 This bandplan presents several potential interference challenges, where technical licence conditions (TLCs) may need to be applied:

- TDD systems operating close to the lower band edge could produce interference into FDD base station receivers operating immediately below 2570 MHz. A 5 MHz restricted block exists between 2570 and 2575 MHz to provide protection against this situation, and a Commission Decision [5] on this band allows the use of an alternative block edge mask for the restricted block in the case where there are additional restrictions on antenna placement. Ofcom needs to specify the form of antenna placement restrictions applicable to use of this alternative block edge mask.
- Low power systems will need to comply with requirements to limit unwanted emissions above 2700 MHz, used by radar systems, and below 2620 MHz, used by TDD systems. Our previous report [3] assumed the low power systems occupied the highest channel, but identified that this was not necessarily the optimum placement.
- Low power systems operating in hybrid mode could cause interference to standard power systems. The form of specific restrictions will depend on the relative priority between the licensees regarding the overlapping portion of spectrum. Our previous report examined the potential form of such restrictions, but did not quantify the associated interference levels or suggest values for the parameters in the restrictions.
- Low power licensees could cause interference to each other when deploying in a common geographical area. Our previous report examined a wide range of techniques whereby appropriate conventions amongst licensees could manage such interference, but also

showed that in the case of LTE technology there were certain basic limitations arising from control and synchronisation channels which create an increasing overhead as the number of licensees increases. Potential licensees need to understand these limitations in order to assess the potential utility of the licences.

Our findings on all of these issues are studied in some depth in this report.

2.3 Ofcom want to understand the technical issues associated with 2.6GHz spectrum in order to form appropriate technical licence conditions

2.8 The aim of this study is to investigate the technical issues associated with some particular aspects of the award of the 2.6 GHz spectrum in support of the creation of appropriate technical licence conditions. Four areas of study were requested by Ofcom:

A: Restricted TDD blocks
The edges of the unpaired spectrum in 2.6 GHz include 5 MHz *restricted blocks*, which are subject to restrictions on the output power and out-of-block emissions mask in order to protect adjacent FDD systems. These restrictions are specified by a European Commission decision [5]. This decision specified that a less restrictive mask could be applied if the interfering TDD systems were subject to appropriate restrictions on indoor placement and antenna height. The decision did not however specify these restrictions, and Ofcom wish to determine appropriate antenna heights to adequately protect nearby FDD systems while increasing the utility of the restricted blocks.

B: Low Power LTE Frequency Placement
If a low-power shared access spectrum block is awarded in the auction, it may consist of up to 2 x 20 MHz of spectrum with downlink transmissions occurring in the range 2620-2690 MHz. Our previous report on low-power access examined some of the issues associated with interference between that block and adjacent services, but did not reach a firm conclusion on the optimum frequency placement of that block within the paired spectrum. Two particular restrictions have to be observed for such low-power systems:

- They will need to meet a limit set by Ofcom on emissions in the adjacent 2.7 GHz band. Additional restrictions may apply when they are within a given distance of a radar system in this band. For the purposes of this report we have based the study on unwanted emission levels of -45 dBm/MHz Equivalent Isotropically Radiated Power (EIRP) and -65 dBm/MHz EIRP.
- They must meet the limit arising from the European Commission decision that out-of-block emissions do not exceed -45dBm/MHz EIRP in frequencies below 2615 MHz

Ofcom wish to examine the ability of low power access points to meet these limits without requiring modifications relative to standard units designed for the European market. The outcome should be the range of channels which would be in some sense optimal for placement of the low power block.

C: Hybrid Approach to Shared Spectrum
One option for placement of the low power block is partially overlapping a standard power block, allowing both to have access to 2 x 20 MHz in places where mutual interference is low and thereby to maximise the available data rates (assuming LTE technology) or the number of operators who can operate in the same area in the case of low power licensees. When interference does occur, however, it is important that the restrictions which apply are clear to all licensees and effective in limiting service degradation. Ofcom has requested that the specific form of such restrictions be

analysed under the assumption that the standard power licensee takes precedence over the low-power licensees in the shared block.

D: Number of Low Power Licences
We identified in our previous report that there was no specific technical limitation leading to a 'hard' maximum limit on the number of licensees who could share the low power block. However, the presence of control and synchronisation channel overheads will progressively degrade the available capacity in instances of deployments in the same geographical area and the overhead will differ for dedicated low power access compared with hybrid access. Ofcom wish to understand the implications of several low-power licensees sharing spectrum in a geographical area.

2.4 We have adopted a structured methodology with assumptions appropriate to the issues of interest to Ofcom

2.9 Our work in this study was organised into four interdependent workpackages, aligned with Ofcom's study questions:

- **Workpackage A**: Restricted TDD blocks, described in Chapter 4
- **Workpackage B**: Low Power LTE Frequency Placement, described in Chapter 5
- **Workpackage C**: Hybrid Approach to Shared Spectrum, described in Chapter 6
- **Workpackage D**: Number of Low Power Licences, described in Chapter 7

2.10 Figure 2 illustrates how these workpackages relate to the interference modes and frequency placement issues identified in Section 2.2.

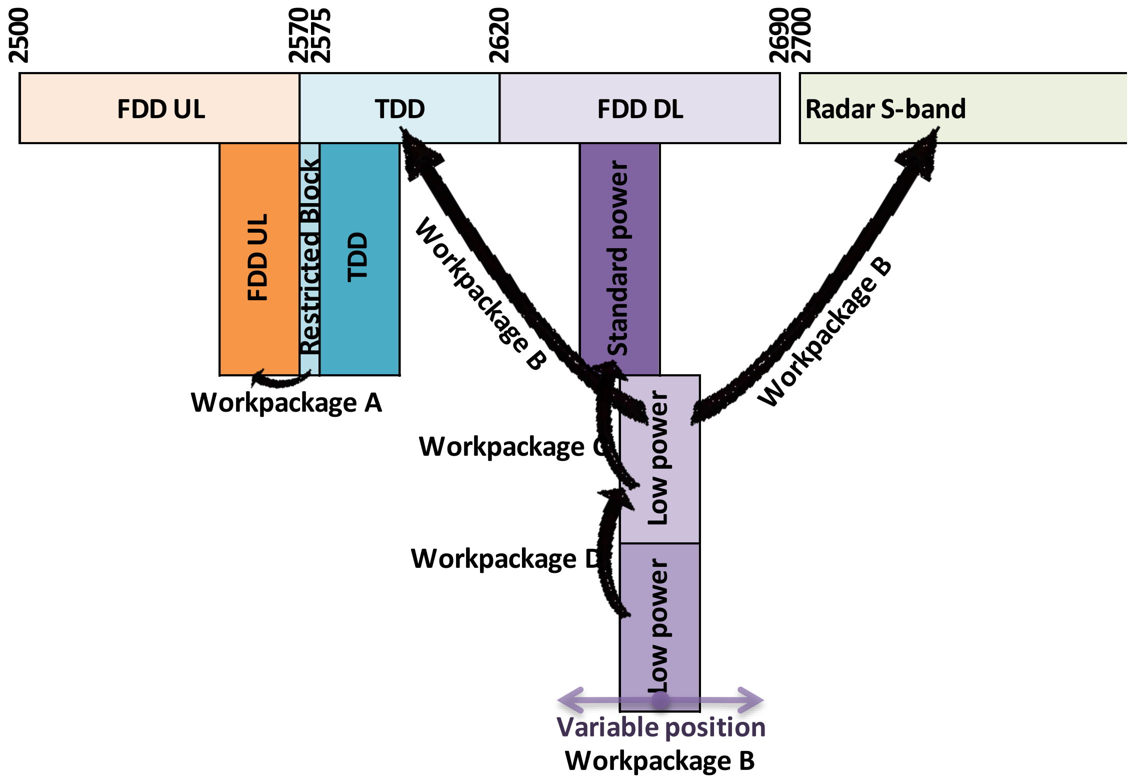

Figure 2: 2.6 GHz bandplan, showing some potential interference paths

2.11 Both workpackages A and C rely on an interference criterion detailed in the Appendix at Section 8.

2.12 Throughout this report we have adopted parameters and modelling approaches which are consistent wherever appropriate with our previous work in [3] and with Ofcom's wider technical analysis in [4].

2.13 In places where additional assumptions are required, we have used references from 3GPP and discussions with particular vendor stakeholders to inform our choices.

2.14 Although licences for this spectrum are expected to be technology neutral, Ofcom requested that systems complying with the 3GPP LTE standards should be the basis of our analysis.

3 Summary results and recommendations

3.1 Our main findings are summarised here organised according to our four main workpackages.

3.1 A: Restricted TDD blocks

3.1.1 Our approach

3.2 We examined interference which could be caused by TDD systems operating in the restricted block in unpaired spectrum into adjacent frequency 10 and 20 MHz Frequency Division Duplex (FDD) systems operating indoors or outdoors with various macro, pico and femtocell installations. In each case we judged that interference would be significant if it was as large as the interference level which the FDD base station receiver could expect from other FDD operators occupying the adjacent channel. We examined the interference levels which would be produced when the alternative Block Edge Mask (BEM) specified by European Commission Decision 2008/477/EC [5] applies.

3.3 We found that a combination of height and separation distance from FDD base stations could be effectively applied to the TDD deployments to provide adequate protection. Our recommendations follow and the associated separation distances are summarised in Table 2.

3.1.2 Our recommendations

3.4 Commission Decision 2008/477/EC [5] states use of the alternative BEM is allowed in cases where the antenna is indoors or below a certain height. We recommend a combination of antenna height (for outdoor antennas) and a separation distance restriction.

3.5 If the separation distance is smaller than the values summarised in Table 2, the alternative BEM does not provide adequate protection to the adjacent channel FDD installations.

3.6 The channel bandwidth does not lead to a sufficiently large impact on the required separation distance so as to require a variation in the recommended separation distances or heights. The values of Table 2 are sufficient for both channel sizes.

Outdoor TDD installations

3.7 The Commission Decision 2008/477/EC [5] requires a height restriction for outdoor antennas if the alternative BEM is used.

3.8 The antenna height of outdoor installations of TDD systems, complying with the restricted in-block power and the alternative out-of-block mask, should be a maximum of 12m in order to reduce the probability of long line of sight paths to FDD base stations.

3.9 The geographical distance of outdoor TDD installations from macro FDD base stations should be at least **160m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

3.10 The geographical distance of outdoor TDD installations from micro FDD base stations should be at least **40m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

3.11 In the case that a TDD system is located closer to an FDD system than the recommended distance, then a site survey is required, to assess whether excessive interference is caused at the FDD base stations. A TDD system can be sited closer than the recommended distance, if there is adequate protection to the FDD systems.

Table 2: Separation distance recommendation for use of the alternative Block Edge Mask. Maximum aggressor antenna height 12m.

Victim scenario	Victim equipment class					
	Wide area base station		LABS		Home eNodeB	
	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
Outdoor macro	160	70				
Outdoor micro			40	20		
Indoor office pico			20	20	10	10
Indoor residential femto					10	10

Indoor TDD installations

3.12 The Commission Decision 2008/477/EC [5] does not require a height restriction for indoor TDD installations if the alternative BEM is used, however similar licence conditions are recommended, as in the outdoor case.

3.13 The antenna height of indoor installations of TDD systems, complying with the restricted in-block power and the alternative out-of-block mask, does not require regulation in the technical licence conditions.

3.14 The geographical distance of **indoor TDD** installations from **macro FDD** base stations should be at least **70m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

3.15 The geographical distance of **indoor TDD** installations from **micro FDD** base stations should be at least **20m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

3.16 In the case that a TDD system is located closer to an FDD system than the recommended distance, then a site survey is required, to assess whether excessive interference is caused at the FDD base stations. A TDD system can be sited closer than the recommended distance, if there is adequate protection to the FDD systems.

3.17 It is unlikely to be feasible to coordinate residential femto installations. However, the recommended separation distance is adequately short so as to assume that no additional restriction on the placement is needed.

3.18 The above recommendations are based under the assumption that there is a strong interfering path between the TDD and FDD installations, and therefore these recommendations are not a hard limit if it can be shown that the strong interfering path does not exist, for example because there is a large degree of site shielding to avoid the possibility of a strong line of sight interfering path.

3.19 For example, the assumed penetration depth in indoor scenarios represents a concrete external wall with a window. However, the TDD and FDD installations may be protected by multiple wall penetrations, so that in practice their separation distance could be agreed to be less than the recommended values in Table 2.

3.20 If there is an agreement between the relevant TDD and FDD operators for specific installations, the recommended separation distance could be relaxed.

3.2 B: Low-power LTE frequency placement

3.2.1 Our approach

3.21 We examined the ability of low-power access points which meet relevant 3GPP specifications to also meet the additional restrictions which may apply in this band. In particular, they should meet the EC requirement from EC decision 2008/477/EC [5] of -45dBm/MHz EIRP below 2615 MHz and the limits on unwanted emissions for the protection of radar above 2700 MHz. For the purpose of this study we have considered both a -45dBm/MHz EIRP limit and a limit of -65dBm/MHz EIRP.

3.22 We examined likely transmitter architectures for low power base stations meeting the3GPP requirements, validating our assumptions via stakeholder discussions, and modelled the likely emissions according to the most likely architectures. We then determined what additional measures, such as filtering or reduction in EIRP below the proposed 30dBm, would be necessary in order to meet these limits on unwanted emissions, and how these varied with the channel placement.

3.2.2 Our findings and recommendations

3.23 These recommendations assume that Ofcom licenses a maximum EIRP of 30dBm for Home and Local Area BS in UK.

3.24 Ofcom is proposing an unwanted emissions limit of -45 dBm/MHz above 2700 MHz. However, in certain circumstances it would be advantageous for unwanted emissions to be kept below this regulatory limit (e.g. to reduce the need for detailed coordination with Radar operators close to Radar sites). For this reason Ofcom has asked us to study the impact of meeting two unwanted emissions values: the proposed -45 dBm/MHz regulatory limit and a lower level of -65 dBm/MHz.

3.25 For 10MHz channels, needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

3.26 For 10MHz channels needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz.

3.27 For 20MHz channels needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2660MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

3.28 For 20MHz channels needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2670MHz. This may mean the vendor requires additional RF filtering to meet this unwanted emissions level.

3.29 Using these recommended frequency ranges, the implication on access point vendors is likely to be:

- For BS using 10MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after Power Amplifier (PA) device or improved duplexer filter

  - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
  - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS

- For BS using 10MHz channels, having to meet an unwanted emissions level of -45dBm/MHz:
  - For 30 dBm EIRP, vendors can probably use an unmodified but well-designed BS
  - For 27 dBm EIRP, vendors can probably use an unmodified but well-designed BS
  - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS
- For BS using 20MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
  - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
  - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
  - For 20 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
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  - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
  - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
  - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS.

3.3 C: Hybrid approach to shared spectrum

3.3.1 Our approach

3.30 We have examined the various means by which low power licensees can protect a standard power licensee from interference in the shared 2 x 10MHz spectrum block. Varying degrees of information sharing and measurements can assist in this process and we have analysed and highlighted the relative merits of these.

3.31 We have also conducted specific analysis of the extent of potential downlink interference, which could create interference zones to standard power mobiles in limited regions around low power access points and of uplink interference which could desensitise standard power base stations. In each case we have suggested coordination rules which we believe could be effective in limiting the extent of the interference caused, given an appropriate choice of parameters.

3.3.2 Our recommendations

3.32 When using the hybrid approach to shared spectrum, the low power base station and mobile terminal stations (UEs) should control their transmit power based on measurements in order to limit interference to the standard power network to within agreed acceptable limits.

3.33 **For the downlink**: The Low Power Base Station (LPBS) evaluates power received from the Standard Power Base Station (SPBS), and sets its EIRP according to the following algorithm:

$EIRP_{LPBS}$ = min {$EIRP_{MAX}$, PR_{SP} + Offset - margin} (in dBm)

where:

- $EIRP_{MAX}$ is the regulatory limit for the given LPBS deployment scenario
- PR_{SP} is evaluated using the network listen function of the LPBS. In practice, the measurement for Long Term Evolution (LTE) will likely be the Reference Signal Received Power, which will represent only a fraction of the total received power across the 20MHz standard power channel. This measurement should be scaled to represent the total received power.
- Offset is chosen to give a particular zone size for a given zone criterion.
- The margin represents power setting error and is assumed to be the same for the LPBS as for the User Equipment (UE) (11dB)
- $EIRP_{LPBS}$ is the total EIRP of the LPBS over the whole 20MHz Low Power (LP) channel.

3.34 The above rule will limit outdoor interference zones to 50m, where an interference zone is defined by the locus of points where PRSP/PRLP > 0dB, given the parameter assumptions used in our study.

3.35 **For the uplink**: The LPBS monitors SPBS-LPUE coupling loss based on measurements made by the LPUE, and limits the LPUEs transmit power according to the following algorithm:

Maximum LPUE Power = min(Coupling Loss- 67.5dBm - margin, UE Power limit) (in dBm)

where:

- Coupling loss is determined by the LPUE from measured power from the SPBS and the transmitted power which can be determined from the system information broadcast, which must be read before any measurement can take place.
- Margin represents the power setting ability of the UE, and includes the measurement uncertainty. A figure of 11dB is taken from 3GPP specifications.
- UE power limit is +23dBm ±2dB, as specified by 3GPP
- Where per UE power capping is not possible or appropriate, a per cell power cap may be applied based on the worst case (lowest) coupling loss measurement.

3.36 Where the LPBS and LPUE are unable to make measurements of the SP network – e.g. in the case where a non-compatible technology is deployed, the LPBS must not be deployed within the coverage area of any SPBS. Coverage area size will vary depending on the class of SPBS. Wide area SPBSs which transmit more power will incur wider exclusion zones for LPBSs. It may be necessary for the standard power licensee to share information with LP licensees as to the location and class of deployed SPBSs.

3.4 D: Number of low power licences

3.4.1 Our approach

3.37 We have analysed the structure of control and synchronisation channels in LTE to determine the extent of potential degradation to traffic capacity which would arise from minimising degradation to these channels in geographical areas with multiple low power operators. We used this analysis to determine both soft and hard limits on the number of licensees in such situations.

3.4.2 Our findings

3.38 Whilst there is no fundamental limit to the overall number of licenses that can be awarded for the low power shared access, there are limits on the number of cells from different licensees that can operate with overlapping coverage. In order that multiple licensees sharing overlapping spectrum can provide services over the same geographical area, the Synchronisation Channel (SCH), Broadcast Channel (BCH) and Physical Downlink Control Channel (PDCCH) control channels should be co-ordinated such that they are not transmitted on the same time and frequency resources.

3.39 The SCH and BCH channels are located within the central 6RBs of the carrier bandwidth, and so a combination of time shifting and/or carrier offsetting can be used to avoid transmission on the same resources.

3.40 The PDCCH is transmitted over the entire carrier bandwidth and so time domain shifting is needed to ensure these are not simultaneously transmitted on any cells sharing the same spectrum and geographical area.

3.41 There is a hard limit of 14 co-existing cells that can transmit in overlapping spectrum in the same geographical area whilst avoiding PDCCH transmissions at the same time. However, with this many cells, there would be no resources left for user data. Figure 75 shows the percentage of resources available for user data in the low power shared access channel as a function of co-located low power cells, which provides a soft limit.

4 A: Restricted TDD blocks

4.1 Ofcom would like to determine licence conditions to protect FDD systems from TDD systems transmitting in the restricted spectrum blocks

4.1 This section deals with the level of interference which can potentially be caused by the use of the restricted unpaired spectrum blocks in use for Time Division Duplex (TDD) technology and Frequency Division Duplex (FDD) receivers operating in the immediately adjacent paired spectrum.

4.2 Some background on the Commission Decision 2008/477/EC [5], which initiated this study question, is first provided. The study questions are then laid out, followed by the definition of the response approach and the underlying assumptions. A list of the scenarios that are considered is provided, and the associated parameter assumptions are discussed.

4.3 The chapter continues with the calculation of the interference power, based on the use of the alternative Block Edge Mask (BEM) in the restricted TDD block. An outline of the results is provided with a detailed description of the interference that occurs in each modelled scenario.

4.4 Each scenario is then analysed individually. Scenarios are broadly categorised with respect to Line Of Sight (LOS) between the FDD and TDD installations. The probability of LOS occurrence is discussed in more detail.

4.5 Conclusions and recommendations for associated technical licence conditions are provided at the end.

4.2 Background

4.6 This section provides a brief background for this study question. First the properties of the restricted TDD blocks are defined. The alternative BEM is then discussed as part of a previous Ofcom proposal on restricted TDD blocks. The alternative BEM is then presented.

4.2.1 Background on restricted TDD blocks

4.7 This study concerns restricted blocks in the 2.6 GHz spectrum. Commission Decision 2008/477/EC [5] includes restricted blocks for use

a) between TDD (unpaired) spectrum and FDD uplink spectrum at 2570-2575 MHz, and
b) between separate TDD licences.

4.8 For the purposes of this study, we were asked to look at interference from the restricted TDD block at 2570-2575 MHz into the adjacent FDD spectrum. Restricted TDD blocks are limited to an in-block power of 25dBm/(5 MHz) Equivalent Isotropically Radiated Power (EIRP), which is lower than the mobile terminal station limit of 31dBm/(5 MHz) Total Radiated Power but slightly higher than the 23dBm terminal power specified in the 3GPP standard 36.101 [6]. Additionally, the Commission Decision provides an alternative BEM for restricted TDD blocks under certain conditions:

> "In cases where antennas are placed indoors or where the antenna height is below a certain height, a Member State may use alternative parameters in line with Table 5 (the alternative block edge mask), provided that at geographical borders to other Member States Table 1

(baseline requirement of -45dBm/MHz) applies and that Table 4 (in-block EIRP limit for restricted blocks) remains valid nationwide.”

4.9 The alternative block edge mask is more restrictive than the Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access terminal emissions mask in the 5 MHz immediately adjacent to the restricted block (assuming a 23dBm terminal). Beyond 5 MHz the UTRA terminal mask becomes more stringent.

4.10 If the conditions on antenna placement are not met, then the baseline level of -45 dBm/MHz applies to unwanted emissions in the spectrum below 2570 MHz from restricted TDD blocks. Neither the Commission Decision nor the European Conference of Postal and Telecommunications Administrations (CEPT) Report 19 [7] that developed the block edge mask requirements specify or provide suggested ranges for the range of antenna heights where this could be applied.

4.11 Thus this chapter aims to establish appropriate values for the heights and associated parameters to provide adequate protection of FDD systems in the vicinity of TDD transmitters which occupy the restricted block and which comply with the alternative block edge mask.

4.2.2 Previous Ofcom proposals on restricted TDD blocks

4.12 In the conditions for the award of the 2500 to 2690 MHz band that Ofcom set out in the April 2008 Information Memorandum [8], the alternative mask could be used in cases where antennas are either:

a) placed indoors and are at a height no greater than 10 metres above ground level, or
b) placed outdoors and are at a height no greater than 4 metres above ground level.

4.13 Subsequent to the publication of the April 2008 Information Memorandum Ofcom received comments that the use of the alternative mask at these permitted antenna heights could lead to unacceptable interference into FDD base station receivers. As part of the preparation for the current proposals, Ofcom has therefore reconsidered the technical conditions applicable to the use of this mask.

4.2.3 Description of the TDD block edge masks

4.14 The block edge mask for restricted blocks is:

- Maximum in-block limit of 25 dBm/(5 MHz) EIRP
- Baseline out of block limit of -45 dBm/MHz EIRP

Table 3: Alternative Block Edge Mask (BEM)

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
Start of band (2500 MHz) to -5 MHz from lower block edge	-22 dBm	1 MHz
-5 MHz to -1 MHz from lower block edge	-18 dBm	1 MHz
-1 MHz to -0.2 MHz from lower block edge	$-19 + 15(\Delta_F + 0.2)$ dBm	30 kHz
-0.2 MHz to 0 MHz from lower block edge	-19 dBm	30 kHz
0 MHz to 0.2 MHz from upper block edge	-19 dBm	30 kHz
0.2 MHz to 1 MHz from upper block edge	$-19 - 15(\Delta_F - 0.2)$ dBm	30 kHz
1 MHz to 5 MHz from upper block edge	-18 dBm	1 MHz
5 MHz from upper block edge to end of band (2690 MHz)	-22 dBm	1 MHz
Where: Δ_F is the frequency offset from the relevant block edge (in MHz)		

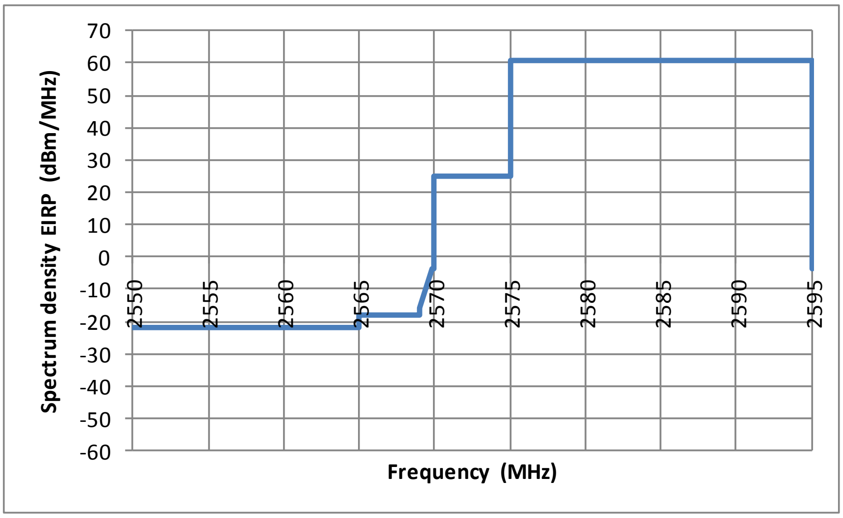


Figure 3 Alternative Block Edge Mask (BEM)

4.15 The alternative block edge mask for base stations in restricted blocks with additional restrictions on antenna placement is given in Table 3 and plotted in Figure 3.

4.3 Ofcom's Study questions

4.16 Ofcom provided the following questions as the basis for this study.

4.17 Provide a comparative analysis of interference into FDD base station receivers from the two sets of conditions, for the following range of antenna heights:

- Indoor antennas at a range of heights up to 10m above ground level
- Outdoor antennas at a range of heights up to 4m above ground level

4.18 Assume the FDD base station receiver is a Long Term Evolution (LTE) system, using the block at 2560 to 2570 MHz (in the case of 10 MHz systems) and the block 2550 to 2570 MHz (in the case of 20 MHz systems). CEPT Report 19 [7] does not take account of the FDD receiver's adjacent channel selectivity; it is only concerned with the emissions falling within the assigned FDD spectrum block. This approach should also be adopted for the present study.

4.19 A range of typical FDD base stations should be considered, with reasonable assumptions about their antenna placement (to be agreed with Ofcom):

- Macrocell base station
- Microcell base station
- Picocell base station (indoor and outdoor installations)
- Low-power LTE base station (as outlined in consultation on proposals for the award of 800 MHz and 2.6 GHz spectrum)

4.20 Based on the analysis, make recommendations on:

a) The maximum antenna height for indoor installations of TDD base stations complying with the restricted in-block power and the alternative out-of-block mask

b) The maximum antenna height for outdoor installations of TDD systems complying with the restricted in-block power and the alternative out-of-block mask

c) Any other restrictions on antenna placement (within the scope permitted by the Commission Decision)

4.4 Approach and assumptions

4.21 In order to analyse the interference into FDD base stations from TDD installations we have adopted a methodology based on link budget calculations and on existing work from the LTE standardisation process.

4.22 The study questions require quantification of the amount of interference into FDD base station receivers (victim) from TDD transmitters (aggressor). In order to answer the study question we work 'backwards' on the interference path:

4.22.1 First, we determine the amount of interference at the FDD receiver that is considered acceptable. This level was selected based on the LTE standardisation process [9], where the interference from an FDD Up Link (UL) channel to an adjacent FDD UL channel was investigated. The selected interference level leads to a maximum of 10% throughput degradation for 95% of the users. The details of this process are provided in the Appendix.

4.22.2 Depending on the location and equipment type for the aggressor and victim (e.g. indoor/outdoor, macro/micro/pico/femtocell, LOS/ (Non Line Of Sight) NLOS etc.) we select an appropriate propagation model. Since one of the purposes of the Technical Licence Conditions (TLC) is to prevent adverse interference conditions, the propagation model assumptions favour strong interference paths.

4.22.3 We then calculate the aggressor's emissions into the adjacent channel, which will be received within the channel filter of the victim receiver.

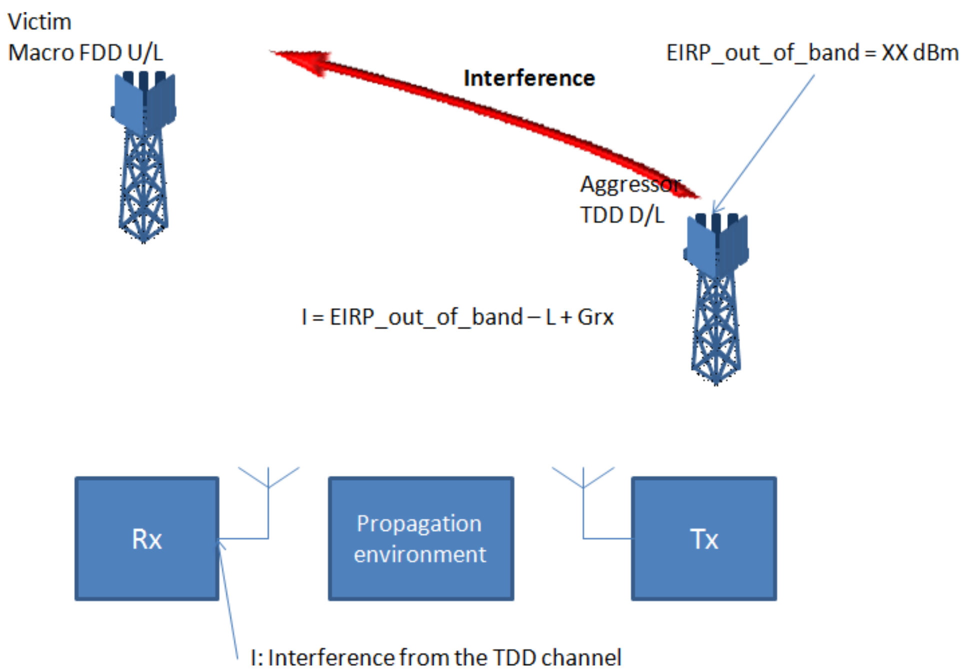


Figure 4 Schematic of the modelled interference

4.22.4 We vary the separation distance between aggressor and victim and derive the maximum acceptable aggressor height, based on the applicable path loss model.

4.23 Figure 4 shows a simple schematic of the aggressor and victim. The aggressor's out-of-band emissions comply with the specifications of the alternative BEM as defined in Figure 3, and are independent of the in-band power.

4.24 The interfering power propagates from the aggressor to the victim, and is received at the FDD system antenna. The acceptable level of interference at the victim's antenna connector was selected based on the rationale provided in the Appendix.

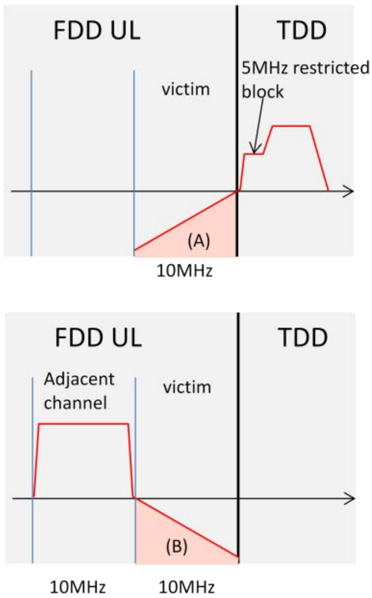


Figure 5 Schematic for the criterion for acceptable interference; 10MHz victim shown

4.25 Figure 5 plots a schematic of the spectrum, where the interference power marked (A) is the in-channel interference from a TDD restricted block operator, and the power marked with (B) is the adjacent channel interference from another FDD uplink based on its emission mask. Power (B) is obtained from 3GPP co-existence simulations for LTE in [9]. For the purpose of Chapter 3.2, we can evaluate (A) from the alternative BEM in different deployment scenarios.

4.26 The variables in the schematic of Figure 4 are chosen as appropriate to the propagation conditions and the victim's receive chain, which depends on the equipment class and deployment type. The variables in the propagation conditions are the propagation model (depending on the type of environment between the FDD and TDD systems), the antenna heights, and the separation distance between the FDD and TDD systems.

4.27 Since the output of this study is the height of the aggressor antenna, all the other parameters are either fixed to a specific value that is typical of such installations, or varied to create a series of scenarios. Table 4 summarises the parameters that were used in this study and the sources and rationale for our choices. Section 4.5 analyses the scenarios identified.

Table 4: Table of parameters

Name	Unit	Value(s)	Details
Aggressor Parameters - TDD, Outdoor/Indoor, 10/20MHz			
Name	**Unit**	**Value(s)**	**Details**
Integrated power from the alternative mask (EIRP)		-9.0dBm/10MHz, -8.2dBm/20MHz	Calculated in Section 4.6
Frequency Band	GHz	2.6	Study input
Antenna Height	m		Study output
Cable, Combiner and Connector Losses	dB	0	Assumption in line with [4]
Bandwidth	MHz	10/20MHz	Study input
Duplex operation		TDD	Study input
DL:UL time ratio	Ratio	N/A	Downlink heavy (worst-case). We are interested in modelling the interference from TDD downlink.
Outdoor/Indoor		Outdoor/Indoor	Study input
Adjacent Channel Interference		Ofcom alternative BEM	Study input
Downtilt	deg	N/A	Boresight assumed. The attenuation due to vertical pattern is dependent on the antenna height and the downtilt. The TLC would not be able to prohibit the aggressor pointing boresight at the victim.
Vertical pattern		omni	
Horizontal pattern		omni	
Victim Parameters per equipment class – Wide area base station			
Name	**Unit**	**Value(s)**	**Details**
Frequency Band	GHz	2.6	Study input
Bandwidth	MHz	10/20MHz	Study input
Duplex operation		FDD	Study input
Antenna height	m	25	Assumption in line with [4]
Antenna gain	dBi	19.1	Kathrein 742 265 multi-band antenna in line with [4] – extrapolated to 2600 MHz
Maximum allowable interference	dBm	-67.5	Calculated in the Appendix
Victim Parameters per equipment class – Local Area Base Station (LABS)			
Name	**Unit**	**Value(s)**	**Details**
Frequency Band	GHz	2.6	Study input
Bandwidth	MHz	10/20MHz	Study input
Duplex operation		FDD	Study input
Antenna height	m	15	Assumption in line with [3], maximum antenna height for LABS
Antenna gain	dBi	3 (indoors) 6 (outdoors)	Assumption in line with [3]
Maximum allowable interference	dBm	-67.5	Calculated in the Appendix

Name	Unit	Value(s)	Details
Victim Parameters per equipment class - Home eNodeB			
Name	**Unit**	**Value(s)**	**Details**
Frequency Band	GHz	2.6	Study input
Bandwidth	MHz	10/20MHz	Study input
Duplex operation		FDD	Study input
Antenna height	m	2.5	Assumption in line with [3], one floor above ground level
Antenna gain	dBi	0	Assumption in line with [3]
Maximum allowable interference	dBm	-67.5	Calculated in the Appendix.
Other Parameters			
Name	**Unit**	**Value(s)**	**Details**
Shadow fading for NLOS	dB	90^{th}percentile enhanced value	Log-normal shadow fading assumed in line with [4]
External wall loss	dB	7	Assumption in line with [3]
Distance between walls (indoor public area)	m	13.5m	Assumption in line with [3]
Distance aggressor and victim	m	Variable	Auxiliary parameter

Table 5: Scenarios and equipment classes

Victim scenario	Victim equipment class		
	Wide area base station	LABS	Home eNodeB
Outdoor macro	✓		
Outdoor micro		✓	
Indoor office pico		✓	✓
Indoor residential femto			✓

4.5 List of modelled scenarios

4.28 The interfering power at the FDD receivers from TDD base stations has been investigated in a number of challenging but practically plausible cases. It is noted that these scenarios do not represent the average installation, but simulate plausible but extreme cases which could be avoided by appropriate regulation using an appropriate TLC consistent with the European Commission (EC) decision.

4.29 A large number of distinct scenarios were identified for analysis of the interfering power at the FDD receivers, when considering the possible combinations of the varied parameters. Table 5 summarises the scenarios identified with respect to the victim equipment class.

4.30 The variability of the assumed link budget parameters regarding the equipment class is provided in Table 4. Note that the scenarios cover the plausible equipment class for each cell type. For example the Wide area base station [13] equipment class is expected to be widely used by the industry in macro cell installations, and is assumed to be an unreasonable device type for micro-, pico-, or femto-deployments.

4.31 Other parameters that are varied in different scenarios are the existence or not of line of sight between the aggressor and victim antennas, the channel bandwidth and the indoor or outdoor location of the aggressor.

4.32 The output of modelling for each of the scenarios is the maximum aggressor antenna height, given an assumption about the separation distance between aggressor and victim. In each scenario, the resulting maximum height versus separation distance relation is based on the propagation model selection for this particular scenario. Information about the propagation model for each scenario is provided in Section 4.7.

4.33 Note that the existence or obstruction of line of sight between the aggressor and victim pair is an assumption for each scenario. However, this assumption is critically examined for its plausibility given each scenario.

4.34 For example, in a scenario where the aggressor is assumed to be within line of sight of the victim, the output distances would need to be close, and/or the antenna heights would need to be high for the assumption to be valid.

Table 6: Power in the victim adjacent 20 MHz channel from the alternative Block Edge Mask (BEM)

From (MHz)	To (MHz)	Power (dBm)
2551.0	2565.0	-10.5
2565.0	2569.0	-12.0
Total		**-8.2**

Table 7: Power in the victim adjacent 10 MHz channel from the alternative Block Edge Mask (BEM)

From (MHz)	To (MHz)	Power (dBm)
2560.5	2565.0	-15.5
2565.0	2569.0	-12.0
2569.0	2569.5	-14.5
Total		**-9.0**

4.35 Conversely, in a NLOS scenario, where a NLOS path loss model is used, the separation distances would need to be larger, in order for the environment to have enough clutter to justify the NLOS assumption with high likelihood, and/or the height of the antennas would need to be small.

4.36 The LOS probability that is used in this study is based on the output of a European research project known as Wireless World Initiative New Radio (WINNER) [10]. Implications of the LOS/NLOS choice of path loss model are further discussed at the beginning of Section 4.7.

4.6 Integration of the aggressor power

4.37 The total power of the aggressor emissions within the victim receiver bandwidth can be calculated from the alternative BEM. The total power is found by integrating the power spectral density over the operating bandwidth of the victim as follows:

$$\mathrm{P(aggressor)} = 10\log_{10}\int_{f_1}^{f_2} S(f)\,df \qquad (1)$$

where $S(f)$ is the power spectral density in W/Hz.

4.38 The frequency range of the integral is: $\mathrm{f}_1 = 2551\ \mathrm{MHz}$ and $\mathrm{f}_2 = 2569\ \mathrm{MHz}$ for 20 MHz channels; $\mathrm{f}_1 = 2560.5\ \mathrm{MHz}$ and $\mathrm{f}_2 = 2569.5\ \mathrm{MHz}$ for 10 MHz channels. The limits do not include the guard bands between channels, consistent with 3GPP analysis in [9]. The 3GPP analysis assumes integration over the whole 10MHz channel, but takes into account the effective receiver filtering of the victim User Equipment (UE), which varies depending on the frequency resources the UE is allocated. Thus the guard band is included implicitly rather than explicitly in the integration

4.39 The power is calculated for each of the alternative BEM branches, and the total interference power is summed.

4.40 Table 6 and Table 7 provide the interference power that results from the integration in each frequency range, for 20 and 10 MHz victim channels respectively. Note that in the calculation of this

Table 8: Separation distance required in each modelled scenario. Maximum aggressor antenna height 12m.

Victim scenario	Victim equipment class																							
	Wide area base station								LABS								Home eNodeB							
	Outdoor				Indoor				Outdoor				Indoor				Outdoor				Indoor			
	LOS		NLOS		LOS		NLOS		LOS		NLOS		LOS		NLOS		LOS		NLOS		LOS		NLOS	
	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20
Outdoor macro	139	153	< 139	< 153	62	68	< 62	< 68																
Outdoor micro									31	34	< 31	< 34	14	15	< 14	< 15								
Indoor office pico									10	11	< 10	< 11	11	12	< 11	< 12	7	8	< 7	< 8	8	9	< 8	< 9
Indoor residential femto																	7	8	< 7	< 8	3	3	< 3	< 3

power all the parameters that are relevant to the transmit chain (e.g. antenna gain, connector losses, etc.) have been included, since the alternative mask is expressed in terms of EIRP.

4.7 Overview of results

4.41 This section provides a brief overview of the results from all modelled scenarios. The results are discussed further in the next section.

4.42 Table 8 summarises the results of this interference investigation. For example, if the victim receiver is a 20MHz channel outdoor Wide aera base station within LOS of the TDD aggressor, then their minimum separation distance should be 153m.

4.43 Note that, for the same receiver example, if the aggressor and victim channels were 10MHz, then this distance could be reduced to 139m. However, the difference between 10 and 20MHz is rather small, and a common minimum separation distance could be adopted.

4.44 Note that in the case of NLOS, the required separation distance is smaller compared to when there is LOS between the aggressor and victim. However, for relatively small separation distances the assumption of a NLOS path can be challenged, if the LOS probability is taken into account. For this reason, only the LOS values are provided explicitly in Table 8.

4.45 Also note that based on the interference analysis of this report, the interference shows little variability with the aggressor antenna height. For example the antenna height does not have an impact on the results that are presented in Table 8.

4.46 However, in outdoor scenarios, we expect the effect of the aggressor height not to be completely irrelevant. This is because, in the extreme case where all aggressor installations are sited at a large height, the victim may be within LOS of aggressors over a wide area.

4.47 For the reasons above, and for consistency with the analysis in [3], we suggest in outdoor scenarios that 12m is set as the maximum aggressor antenna height.

4.48 Indoor TDD installations can be sited closer to FDD systems, since the external wall of the building provides additional shielding to the alternative BEM.

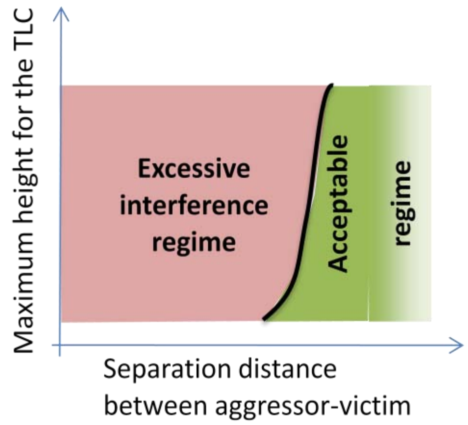


Figure 6 Form of output

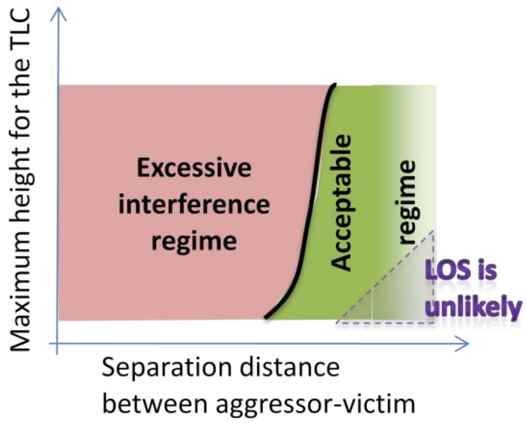


Figure 7 Form of output and LOS likelihood

4.8 Results

4.49 This section begins with a presentation of the form of output and a discussion about the various regimes where the result should be read for conclusions on requirements for the technical licence conditions. Then we present in detail a selection of the scenarios. Finally, we provide comments for the remainder of the scenarios which are not modelled explicitly.

4.8.1 Form of output

4.50 The main output of each scenario is the answer to the study question, the maximum height of the aggressor antenna that leads to an acceptable level of interference and could be used in the relevant TLC.

4.51 The maximum height is determined via the path loss function that is used in each scenario. The other input to the path loss formula is the separation distance between the aggressor and victim. Thus the output of each scenario is the maximum height for the TLC versus the separation distance.

4.52 Depending on the scenario, and the corresponding path loss model, the effect of the antenna height is found to be weaker than the effect of the separation distance. In some cases, e.g. in LOS models, the antenna height is essentially irrelevant and only the distance is explored.

4.53 Figure 6 illustrates the form of output produced for each scenario. The dividing boundary between the two regimes of excessive interference and acceptable interference is the maximum height for the TLC as a function of the separation distance.

4.54 As expected, the interference level is a function of the aggressor's height and the separation distance between the aggressor and the victim. The threshold between acceptable and unacceptable interference regimes and the shape of the threshold is scenario-dependent (e.g. indoor/outdoor, aggressor device type, etc.).

4.55 Note that there is an absolute minimum separation distance, under which the interference is unacceptable regardless of the aggressor's height.

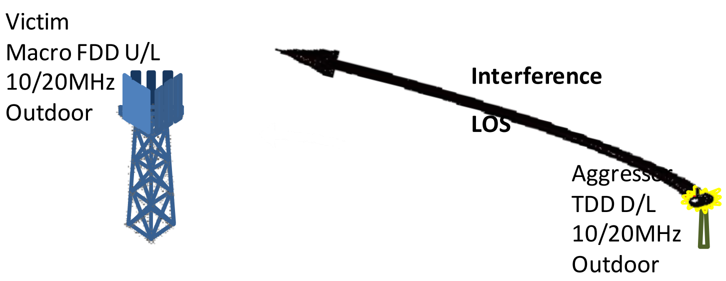


Figure 8 Schematic of the interference link. Aggressor: outdoor, Victim: Macrocell, outdoor macro.

4.56 As analysed in the previous sections, the scenario output curve should be critically compared against the assumption of the existence of an LOS in each scenario. The LOS probability of occurrence is likely to be higher for short separation distances and for increased antenna heights.

4.57 The probability of LOS is also dependent on the dimensions of the cell, i.e. macro-, micro-, pico and femtocells have been found to display different LOS probability with the separation distance since they service different environments.

4.58 Figure 7 plots the same example output as Figure 6, with the addition of a regime within the limits of a purple dotted line where the LOS is highly unlikely. The lower left corner of this regime can be linked to a given level of LOS probability. For example, for a macro deployment the 50th percentile of LOS probability corresponds to about 70 metres [10]. See Section 4.9 for further details.

4.59 For an increasing height the LOS probability is increased, and the 50th percentile is shifted to the right. The amount of shift or the shape of this shift is not defined in [10], so the form of the LOS probability increase with the antenna height is purely indicative, but hopefully reasonable.

4.60 The remainder of this section presents the results in more detail for each of the modelled scenarios. The propagation models that are employed and the scenario parameters are also discussed.

4.8.2 Results: Line of sight with macrocell or microcell victim

4.61 The results from scenarios where the victim is a macrocell or microcell and is within LOS of the aggressor are analysed first. The remainder of the LOS scenarios are then discussed, followed by the NLOS scenarios.

4.8.2.1 Aggressor: outdoor, Victim: Outdoor macrocell

4.62 In this scenario we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver. The aggressor is an outdoor TDD installation and the victim is an outdoor macrocell FDD installation. Figure 8 plots a schematic of the interference link.

4.63 The propagation model that was selected in this scenario is the ITU-R model –LOS branch, lower bound [11], to account for the effect of shadow fading. The rationale for selecting this model is based on worst-case assumptions; the interference link has a path loss that is lower than free space loss to account for waveguiding effects in urban streets and/or strong reflection paths.

4.64 The parameters for this scenario are summarised in Table 4.

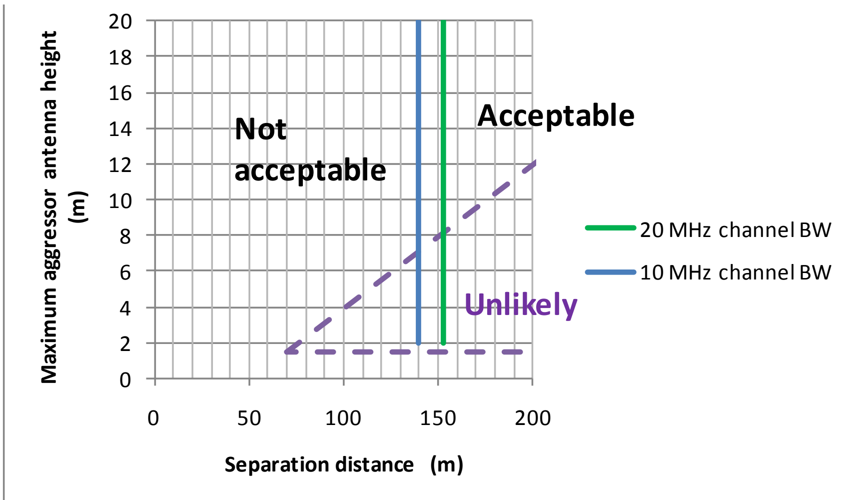


Figure 9 Maximum height vs. separation distance. Aggressor: outdoor, victim: Outdoor macrocell.

4.65 Figure 9 plots the output of this scenario, based on the assumed parameters and propagation model. The maximum height for the TLC vs. the separation distance curve is plotted with solid lines, for the 10 and 20MHz channels.

4.66 The acceptable regime is for separation distance greater than approximately 160m, whereas the aggressor antenna height is irrelevant.

4.67 Note the “unlikely” region, where the LOS assumption becomes rather improbable. In this region the validity of the output from the assumed model is questionable, since NLOS links are more probable. The NLOS scenario is modelled separately.

4.68 Based on the output of this scenario, there is need for a combination of restrictions for the TLC; a minimum separation distance of 160m and a maximum height restriction. Herein it is reminded that the maximum height restriction is applied to avoid the extreme case where all aggressor installations are sited at a large height, in which the victim may be within LOS of aggressors over a wide area.

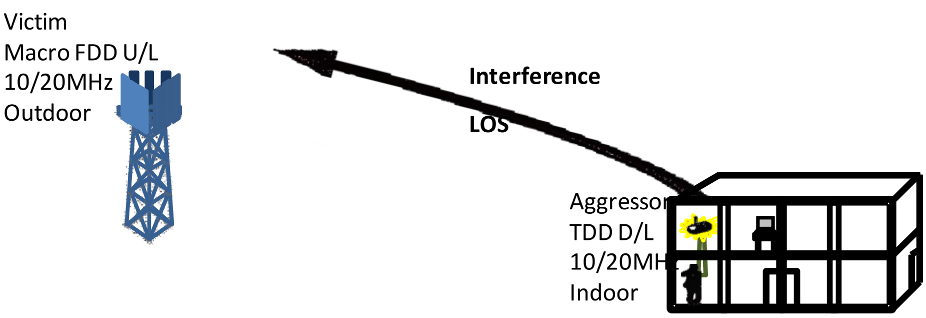


Figure 10 Schematic of the interference link. Aggressor: indoor, Victim: Outdoor macrocell.

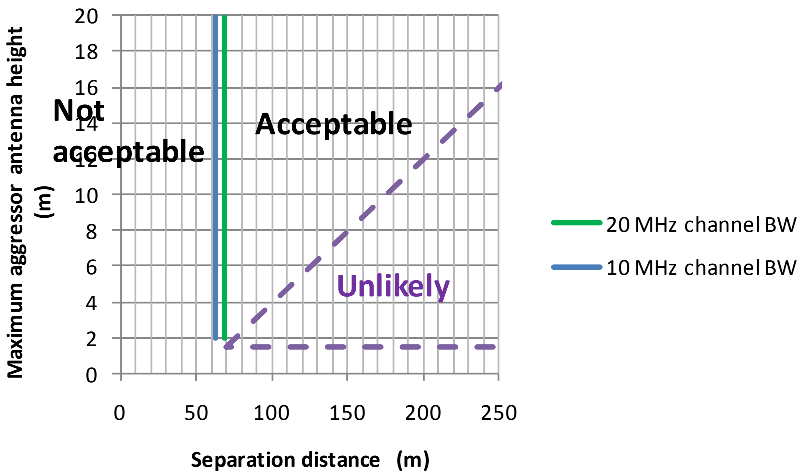


Figure 11 Maximum height vs. separation distance. Aggressor: indoor, Victim: Outdoor macrocell.

4.8.2.2 Aggressor: indoor, Victim: Outdoor macrocell

4.69 In this scenario we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver. The aggressor is an indoor TDD installation and the victim is an outdoor macrocell FDD installation.

4.70 Figure 10 plots a schematic of the interference link. The parameters for this scenario are summarised in Table 4.

4.71 The propagation model that was selected in this scenario is the ITU-R model – LOS branch, lower bound [11], to account for the effect of shadow fading. Penetration loss of a single external wall of 7dB, representing a concrete external wall with a window, was added to the path loss, consistent with [3].

4.72 Figure 11 plots the output of this scenario, based on the assumed parameters and propagation model. This output is similar to that in Figure 9, but the maximum height vs. separation distance curves have been shifted to the left, because of the additional penetration loss.

4.73 The acceptable regime is for separation distance greater than approximately 70m, whereas the aggressor antenna height is irrelevant.

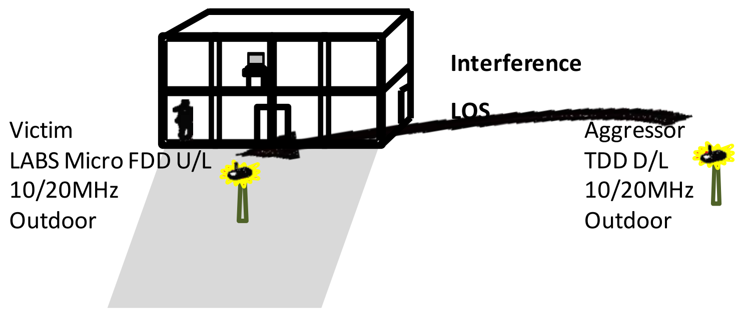


Figure 12 Schematic of the interference link. Aggressor: outdoor, Victim: LABS, outdoor micro.

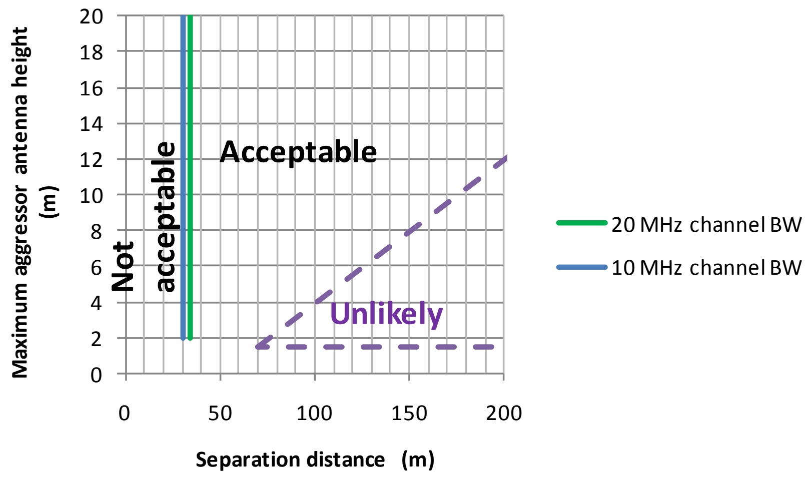


Figure 13 Maximum height vs. separation distance. Aggressor: outdoor, Victim: LABS, outdoor micro.

4.8.2.3 Aggressor: outdoor, Victim: LABS, outdoor micro

4.74 In this scenario we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver. The aggressor is an outdoor TDD installation and the victim is an outdoor micro FDD LABS installation.

4.75 Figure 12 plots a schematic of the interference link. The parameters for this scenario are summarised in Table 4.

4.76 The propagation model that was selected in this scenario is the ITU-R model – LOS branch, lower bound [11], to account for the effect of shadow fading.

4.77 Figure 13 plots the output of this scenario, based on the assumed parameters and propagation model. This output is similar to that in Figure 9, but the maximum height vs. separation distance curves have been shifted to the left, because of the reduced antenna gain at the victim receiver.

4.78 The acceptable regime is for separation distance greater than approximately 40m, while the aggressor antenna height is irrelevant.

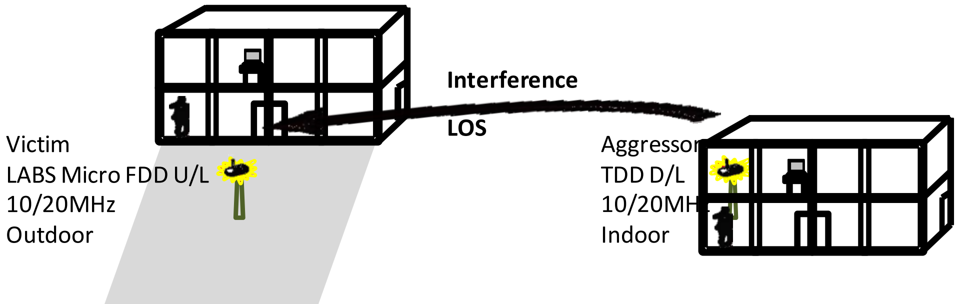


Figure 14 Schematic of the interference link. Aggressor: indoor, Victim: LABS, outdoor micro.

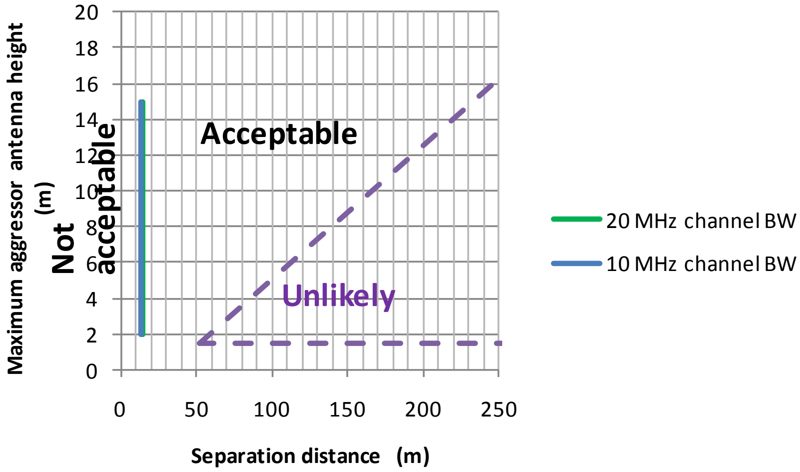


Figure 15 Maximum height vs. separation distance. Aggressor: indoor, Victim: LABS, outdoor micro.

4.8.2.4 **Aggressor: indoor, Victim: LABS, outdoor microcell**

4.79 In this scenario we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver. The aggressor is an indoor TDD installation and the victim is an outdoor microcell FDD LABS installation.

4.80 Figure 14 plots a schematic of the interference link. The parameters for this scenario are summarised in Table 4.

4.81 The propagation model that was selected in this scenario is the ITU-R model – LOS branch, lower bound [11], to account for the effect of shadow fading. Penetration loss of a single external wall of 7dB, representing a concrete external wall with a window, was added to the path loss.

4.82 Figure 14 plots the output of this scenario, based on the assumed parameters and propagation model. This output is similar to that in Figure 9, but the maximum height vs. separation distance curves have been shifted to the left, because of the additional penetration loss and reduced gain at the victim receiver.

4.83 The acceptable regime is for separation distance greater than approximately 20m, whereas the aggressor antenna height is irrelevant.

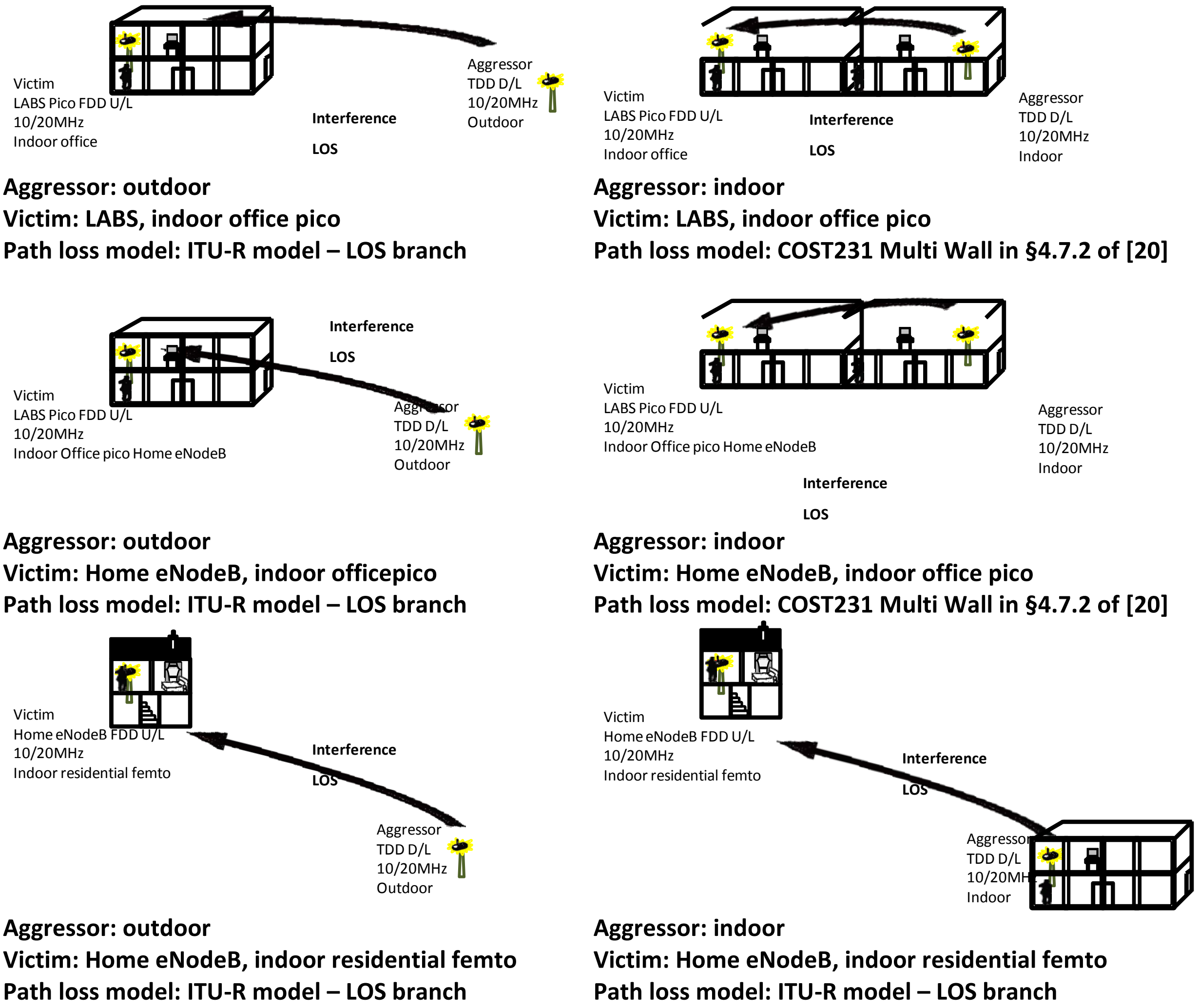


Figure 16 Illustration of the interference paths

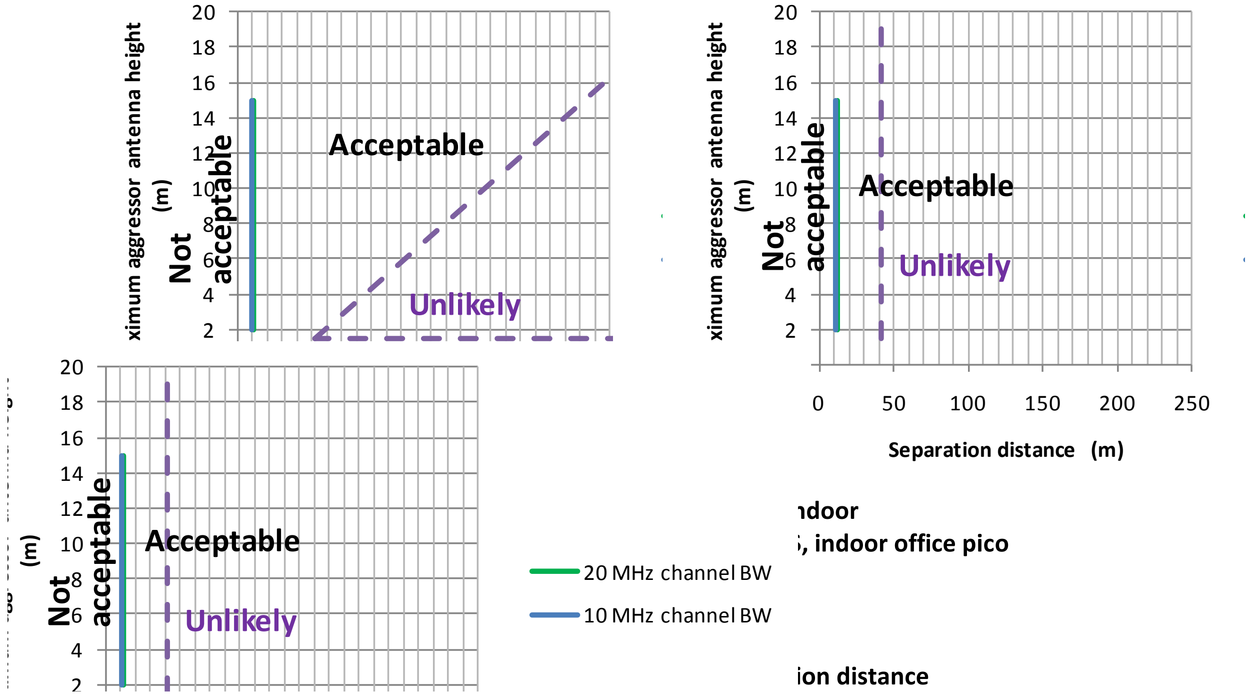
4.8.3 Results: Line of sight with victim picocell or femtocell

4.84 In this section we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver, when the victim is a picocell or femtocell and is within line of sight of the aggressor.

4.85 The position of the aggressor installation (indoor or outdoor) and the victim installation (LABS, indoor office picocell) are plotted for each of these scenarios in Figure 16.

4.86 The propagation models that were selected in these scenarios are the ITU-R [11] and the COST 231 Multi Wall Model in §4.7.2 of [20]. The LOS lower bound branch of the ITU-R was employed, to account for the effect of shadow fading. A penetration loss of a single or double external wall(s) of 7dB, representing a concrete external wall with a window, was added to the path loss, where required, consistent with [3].

4.87 The parameters for this scenario are summarised in Table 4.



4.88 Figure 17 plots selected outputs of the above scenarios, based on the assumed parameters and propagation models. These outputs are similar to those in Figure 9, but the maximum height vs. separation distance curves have been shifted to the left. The separation distance for all scenarios is provided in Table 8.

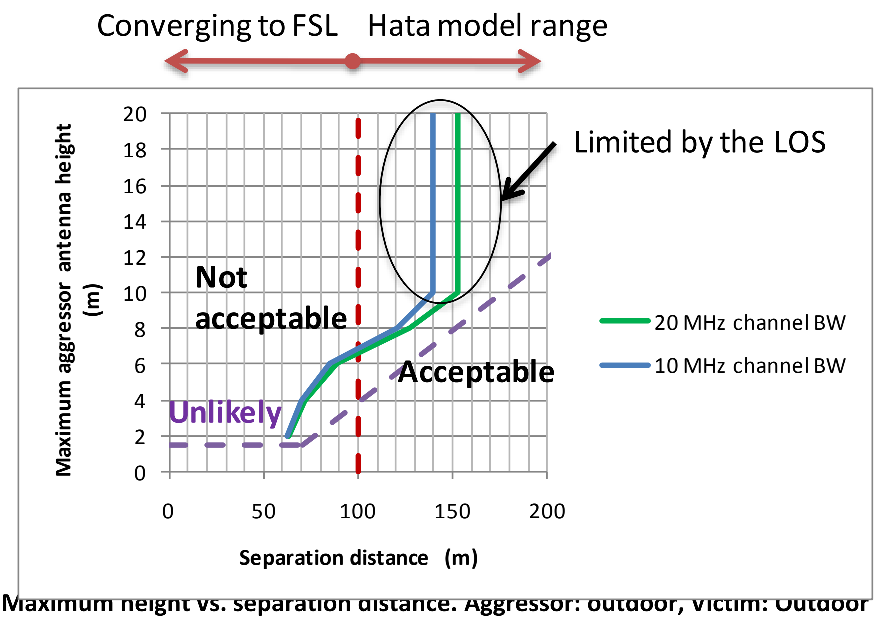


Figure 18 Maximum height vs. separation distance. Aggressor: outdoor, Victim: Outdoor macrocell.

4.8.4 Results: Non line of sight

4.89 In this section we investigate the effect of the aggressor height on the amount of interference that reaches the victim receiver, when the victim is not within line of sight of the aggressor. The positions of the aggressor and victim installations) are the same as these plotted in Figure 8, Figure 10, Figure 12, Figure 14, and Figure 16. The parameters for this scenario are summarised in Table 4.

4.90 In all modelled NLOS scenarios, the resulting recommended separation distance is too short so that the NLOS assumption is highly unlikely. However the output figures from the analysis of selected scenarios are provided below.

4.91 Figure 18 plots the output of the scenario Aggressor: outdoor, Victim: Outdoor macrocell, based on the assumed parameters and propagation model. The maximum height for the TLC vs. the separation distance curve is plotted with solid lines, for the 10 and 20MHz channels.

4.92 The propagation model that was selected is the COST231-Hata SE21 model [19]. A negative shadow fading margin of 10.7dB was added, based on the location variability indicated by [12] for 2.6GHz and the 90th percentile enhanced value, see Table 4.

4.93 The aggressor antenna height affects the received interference in the NLOS case. Thus the acceptable regime is for separation distance greater than approximately 160m, for great aggressor antenna heights, however the separation distance can be reduced for lower antenna heights.

4.94 Note that the model output reverts to the LOS curve when the NLOS median path loss estimation is less than the LOS for the same distance and height. This implies that at that height a NLOS assumption is highly unlikely. Note that the maximum height vs. separation distance curve is within the NLOS-unlikely regime, regardless of the aggressor antenna height.

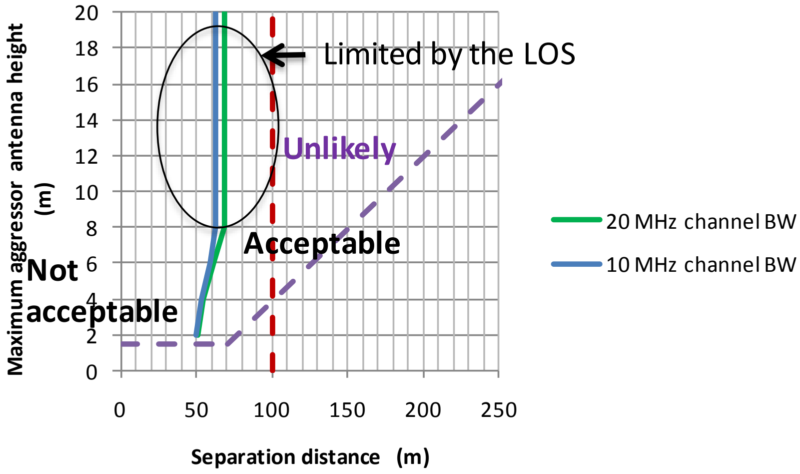


Figure 19 Maximum height vs. separation distance. Aggressor: indoor, Victim: Outdoor macrocell.

4.95 Note also that the median path loss model starts to converge to the free space loss model for separation distances closer than 100m, where the latter is substantially a LOS model. This is another implication that the NLOS assumption is increasingly unlikely in such short distances.

4.96 Due to the decreased likelihood of this scenario occurring, based on the short separation distances, there is no scope for a height or distance obligation recommendation. The output of this scenario exemplifies that, if the aggressor is not within LOS of the victim, then there is a maximum aggressor antenna height, so that NLOS is preserved, for a given separation distance. In other words, the aggressor system can be installed close to the victim, if there is adequate protection to the victim system, which can be verified by a site survey.

4.97 Figure 19 plots the output of the scenario Aggressor: indoor, Victim: Outdoor macrocell, based on the assumed parameters and propagation model. In this scenario the penetration loss of a single external wall of 7dB, representing a concrete external wall with a window, has been added to the path loss. As the propagation losses increase, the separation distance is reduced and thus it becomes even more highly unlikely that the aggressor is not within LOS of the victim.

4.98 The separation distance in other NLOS scenarios is also very short, because of the reduced gains of the victim antenna. It is noted that the resulting separation distance in NLOS scenarios is smaller than that of LOS, see Table 8.

4.9 Line-Of-Sight probability

4.99 The probability of LOS path between a transmitter and a receiver location has been studied in various environments in [10]. In this section we derive from [10] the 50th percentiles for the scenarios that are relevant to this study question.

4.100 The environments that are investigated in [10] are comparable to these in the study question, with the exception of the receiver (victim) height. In this report the victim height can be considerably greater than the receiver UE height of [10]. Therefore, the LOS probability can be assessed by the results of [10] for low victim height, however an appropriate assumption needs to be made for increasing victim antenna height.

Table 9: Line Of Sight (LOS) probability in different environments

Probability	Separation distance (m)		
	Macro	Micro	Indoor open
50%	70.27	52.04	41.19

4.101 Table 9 summarises the 50th percentiles for the scenarios that are relevant to this study question. These separation distance values are employed as thresholds to assist in the robustness of a LOS assumption.

4.10 Recommendations

4.102 Commission Decision 2008/477/EC [5] states use of the alternative BEM is allowed in cases where the antenna is indoors or below a certain height. We recommend a combination of antenna height (for outdoor antennas) and a separation distance restriction.

4.103 If the separation distance is smaller than the values summarised in Table 8, the alternative BEM does not provide adequate protection to the adjacent channel FDD installations.

4.104 The channel bandwidth does not lead to a sufficiently large impact on the required separation distance so as to require a variation in the recommended separation distances or heights. The values of Table 9 are sufficient for both channel sizes.

Outdoor TDD installations

4.105 The Commission Decision 2008/477/EC [5] requires a height restriction if the alternative BEM is used.

4.106 The antenna height of outdoor installations of TDD systems, complying with the restricted in-block power and the alternative out-of-block mask, should be a maximum of 12m in order to reduce the probability of long line of sight paths to FDD base stations.

4.107 The geographical distance of outdoor TDD installations from macro FDD base stations should be at least **160m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

4.108 The geographical distance of outdoor TDD installations from micro FDD base stations should be at least **40m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

4.109 In the case that a TDD system is located closer to an FDD system than the recommended distance, then a site survey is required, to assess whether excessive interference is caused at the FDD base stations. A TDD system can be sited closer than the recommended distance, if there is adequate protection to the FDD systems.

Indoor TDD installations

4.110 The Commission Decision 2008/477/EC [5] does not require a height restriction for indoor TDD installations if the alternative BEM is used, however similar licence conditions are recommended, as in the outdoor case.

4.111 The geographical distance of **indoor TDD** installations from **macro FDD** base stations should be at least **70m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

4.112 The geographical distance of **indoor TDD** installations from **micro FDD** base stations should be at least **20m**, regardless of the TDD system's bandwidth (10 or 20 MHz).

4.113 In the case that a TDD system is located closer to an FDD system than the recommended distance, then a site survey is required, to assess whether excessive interference is caused at the FDD base stations. A TDD system can be sited closer than the recommended distance, if there is adequate protection to the FDD systems.

4.114 It is unlikely to be feasible to coordinate residential femto installations. However, the recommended separation distance is adequately short so as to assume that no additional restriction on the placement is needed.

4.115 The above recommendations are based under the assumption that there is a strong interfering path between the TDD and FDD installations, and therefore these recommendations are not a hard limit if it can be shown that the strong interfering path does not exist, for example because there is a large degree of site shielding to avoid the possibility of a strong line of sight interfering path.

4.116 For example, the assumed penetration depth in indoor scenarios represents a concrete external wall with a window. However, the TDD and FDD installations may be protected by multiple wall penetrations, so that in practice their separation distance could be agreed to be less than the recommended values in Table 8.

4.117 If there is an agreement between the relevant TDD and FDD operators for specific installations, the separation distances could be relaxed.

4.11 Answers to study questions

Study Questions	Answers to Study Questions
Provide a comparative analysis of interference into FDD base station receivers from the two sets of conditions, for the following range of antenna heights: • Indoor antennas at a range of heights up to 10m above ground level • Outdoor antennas at a range of heights up to 4m above ground level	The indoor and outdoor ranges were investigated. The ranges were also extended in the figures to display the effect of the height on the interference.
Assume the FDD base station receiver is an LTE system, using the block at 2560 to 2570 MHz (in the case of 10 MHz systems) and the block 2550 to 2570 MHz (in the case of 20 MHz systems). CEPT Report 19 does not take account of the FDD receiver's adjacent channel selectivity; it is only concerned with the emissions falling within the assigned FDD spectrum block. This approach should also be adopted for the present study.	The acceptable level of interference was calculated for both channels, 10 and 20MHz. The approach is in line with the CEPT Report 19, as requested.

Study Questions	Answers to Study Questions
A range of typical FDD base stations should be considered, with reasonable assumptions about their antenna placement (agreed with Ofcom): • Macrocell base station • Microcell base station • Picocell base station (indoor and outdoor installations) • Low-power LTE base station (as outlined in consultation on proposals for the award of 800 MHz and 2.6 GHz spectrum)	These FDD device types were considered. Results are available for a variable device type.
1.50 Based on the analysis, make recommendations on a) The maximum antenna height for indoor installations of TDD base stations complying with the restricted in-block power and the alternative out-of-block mask b) The maximum antenna height for outdoor installations of TDD systems complying with the restricted in-block power and the alternative out-of-block mask c) Any other restrictions on antenna placement (within the scope permitted by the Commission Decision)	For a full description of the recommendations see Section 4.10.

5 B: Low Power LTE frequency placement

5.1 Ofcom would like to understand the trade-offs associated with frequency placement of low-power devices in the 2.6 GHz band

5.1 This part of the study is a follow-on from the study by Real Wireless on the feasibility of assigning spectrum for low-power shared access systems [3]. It concentrates on the following open issue:

- Optimum placement of the low-power spectrum in the 2.6 GHz band

5.2 The issue of frequency placement represents a trade-off between meeting noise emissions restrictions at both ends of the band and avoiding creating excessive and potentially UK-specific design costs especially in devices intended for mass production.

5.3 In all cases the theoretical transmit power limit is assumed to be 30dBm Equivalent Isotropically Radiated Power (EIRP), consistent with our recommendations in [3] and Ofcom's proposals in [4].

5.2 Ofcom's Study questions

5.4 Ofcom provided the following questions as the basis for this study.

5.5 In association with protection of radar, analyse the feasibility of low-power access points meeting additional block-edge mask limits of (a) -65dBm/MHz EIRP and (b) -45dBm/MHz EIRP above 2700 MHz. Either of the limits may apply, depending on circumstances. We need a view on the impact of assigning spectrum for low-power access points at different frequencies within the 2620 to 2690 MHz band instead of the uppermost block:

- Assume the low-power access points are using 10 MHz Long Term Evolution (LTE) and 20 MHz LTE;
- Include the full range of access points from the low-power LTE study, i.e. residential, office, indoor/outdoor public space, and business park/campus;
- Include as an assumption that the access points will be unmodified units, i.e. standard units placed on the European market, meeting the requirements of the 3GPP standards. Make reasonable assumptions about the performance of the units and unwanted emissions into spectrum outside the 2620 to 2690 MHz operating band, as well as antenna gain. Make reasonable assumptions about any additional filtering that could be included as an installation measure for particular categories of low-power access point;
- At what position in frequency would we need to place the low-power block in order to have a reasonable expectation that emissions from low-power units above 2700 MHz would be below the limits of (a) -65dBm/MHz EIRP and (b) -45dBm/MHz EIRP?
- Bear in mind that access points would also need to meet the baseline requirement from Commission Decision 2008/477/EC that out-of-block emissions do not exceed -45dBm/MHz EIRP in frequencies below 2615 MHz.

5.6 Based on the outcome of this study, make recommendations about the minimum frequency separation between the low-power block and the radar band.

5.3 Emission Requirements

5.3.1 Requirements

5.7 The out-of-block noise emission requirements relevant to this study come from three sources:

a. 3GPP specifications for LTE base stations as expressed by TS36.104, v10.1.0 [13]

b. European Commission requirements, as expressed in the Commission Decision 2008/477/EC [5],

c. Possible Ofcom requirements on unwanted emissions above 2.7GHz.

These requirements are now explained in detail.

5.3.1.1 3GPP requirements

5.8 The 3GPP specifications for LTE base stations – TS36.104, v10.1.0 [13] give out-of-band and spurious emissions requirements for two distinct equipment classes: 1) Home base stations and 2) Local area base stations. The relevant emissions include Adjacent Channel Leakage power Ratio (ACLR), operating band unwanted emissions and wideband spurious emissions.

5.3.1.1.1 3GPP Home base station requirements

5.9 The adjacent channel leakage power ratio requirement limit at offsets 1 x band Width (BW) and 2 x BW is 45dB, where BW in this study refers to the 10MHz or 20MHz channels bandwidth. Either this limit or -50dBm/MHz applies, whichever is the least stringent.

5.10 Within the band and up to 10MHz outside the band (i.e. 2610-2700MHz), excluding the range 10.5MHz either side of the channel, for output powers between 2dBm and 20dBm, the emissions limit is (P-52dB)dBm/MHz, where P is the transmitter output power. So, for an output power of 20dBm, the noise emissions limit is -32dBm/MHz.

5.11 The spurious emissions requirements for Category B equipment between 1GHz and 12.75GHz (excluding 2610-2700MHz) is -30dBm/MHz.

5.3.1.1.2 3GPP local area base station requirements

5.12 The adjacent channel leakage power ratio requirement limit at offsets 1 x BW and 2 x BW is 45dB, where BW in this study refers to 10MHz or 20MHz channels. Either this limit or -32dBm/MHz applies, whichever is the least stringent.

5.13 Within the band and up to 10MHz outside the band (i.e. 2610-2700MHz), excluding the range 10.5MHz either side of the channel, the emissions limit is -37dBm/100kHz, equivalent to -27dBm/MHz.

5.14 The spurious emissions requirement for Category B equipment between 1GHz and 12.75GHz (excluding 2610-2700MHz) is -30dBm/MHz.

5.3.1.2 European Commission requirements

5.15 The out-of-block EIRP block edge mask specified by European Commission Decision2008/477/EC [5] is as follows:

- For frequencies allocated to FDD down link and +/- 5MHz outside the range of frequency blocks allocated to Frequency Division Duplex (FDD) down link, the maximum mean EIRP is +4dBm/MHz.
- For frequencies in the band 2500-2690MHz not covered by the definition above, the maximum mean EIRP is -45dBm/MHz.

5.3.1.3 Ofcom requirements for the protection of radar

5.16 Additional requirements are under consideration in the UK for protection of air traffic control and military radar receivers, which use frequencies above 2700MHz as shown in Ofcom document [4]. In certain circumstances it would also be advantageous for unwanted emissions to be kept below the regulatory limit (e.g. to reduce the need for detailed coordination with Radar operators close to Radar sites). For the purposes of this study, the following limits on unwanted emissions above 2700MHz were used in the analysis:

- -65dBm/MHz EIRP, and
- -45dBm/MHz EIRP.

5.3.1.4 Combined 3GPP, EC and Ofcom requirement

Figure 20 illustrates the combination of all the above requirements.

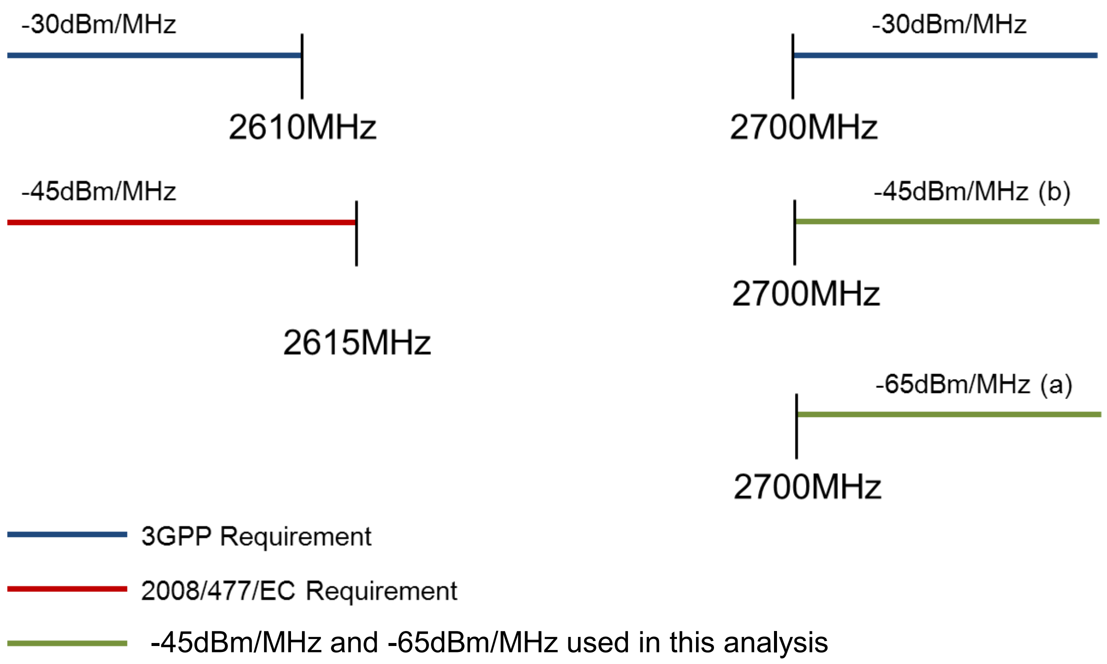


Figure 20 Combination of 3GPP, EC and Ofcom requirements

5.4 *Our approach*

5.17 The problem was approached initially by considering the likely options for design of a low power base station transmitter. Three architectural options were considered. Discussions with some stakeholders were used to establish which of these options were most likely in equipment complying with the 3GPP standard and the impact of varying the requirements on the design. This information enabled us to set up a noise model for a Transmitter (TX) architecture. We modelled a standard base station case representative of a typical base station's noise performance and then a modified base station with uprated filter performance. The models included noise contributions from the In-phase/Quadrature (IQ) modulator noise floor, the Power Amplifier (PA) module adjacent channel leakage or spectral regrowth, and the output filtering selectivity. The model enabled an estimation of the noise output versus frequency for 10MHz or 20MHz channels centred on each possible licence frequency for typical and modified Base Stations (BS).

5.4.1 Transmitter architecture

5.18 The following architectures are common in base stations. Architecture (1), often called 'direct conversion', is cheaper and lends itself well to chipset integration. Better noise performance is possible with architecture (3) as the mixer can be of high local oscillator drive level; however, architecture (1) can provide adequate performance for 3GPP LTE requirements.

5.4.1.1 IQ modulator with baseband digital-analogue converters – Architecture (1)

5.19 Figure 21 below shows a direct conversion transmit architecture, as well as an improved architecture with additional output filtering.

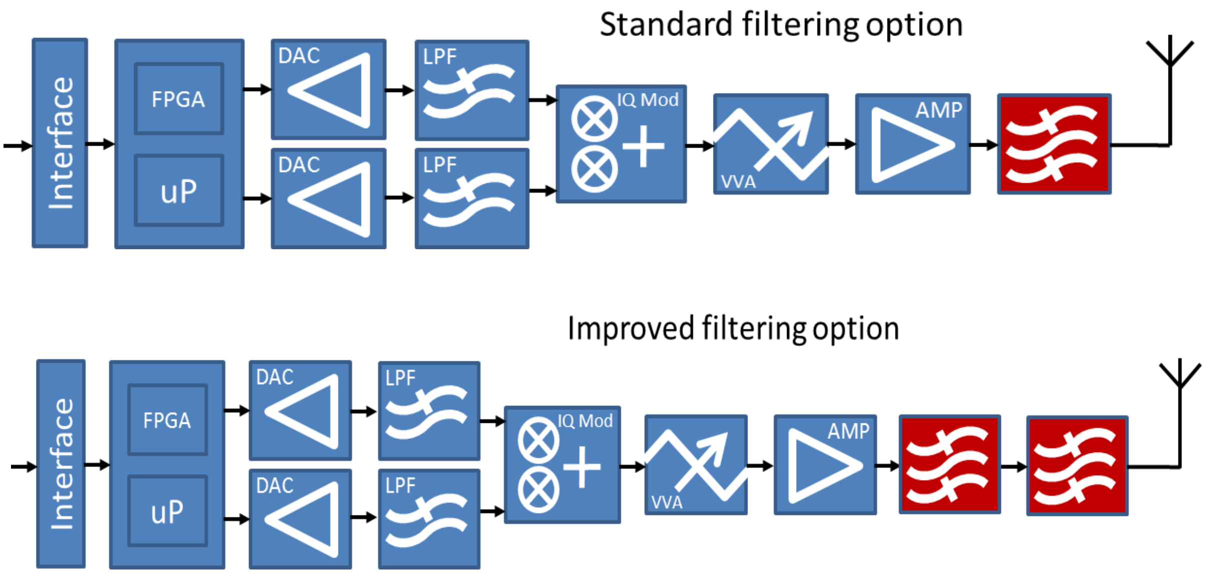


Figure 21 Transmitter architecture (1) – IQ modulator with baseband DACS

5.4.1.2 Bandpass digital-analogue converters with IQ modulator – Architecture (2)

5.20 Figure 22 shows a transmit architecture which uses a bandpass digital-to-analogue converter, as well as an improved architecture with additional output filtering.

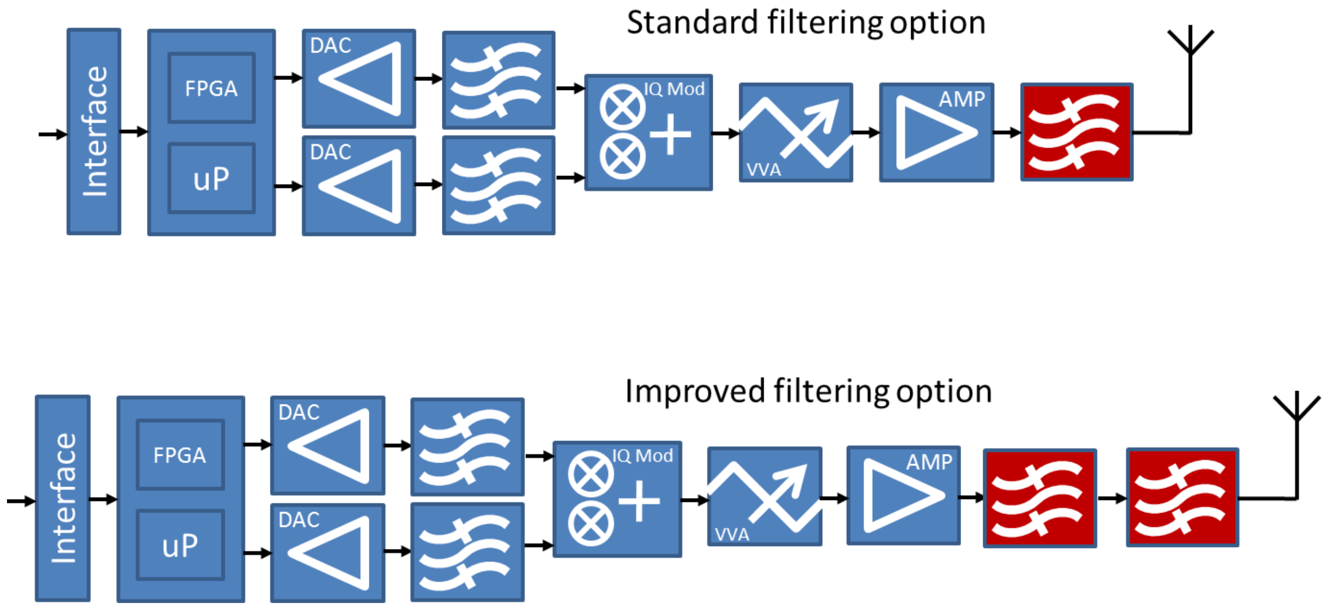


Figure 22 Transmitter architecture (2) – IQ modulator with bandpass digital-analogue converters

5.4.1.3 Bandpass intermediate frequency (IF) digital-analogue converter with Mixer upconvertor – Architecture (3)

5.21 The following block diagrams shows a transmit architecture using a mixer upconverter as often used in macrocell base stations, as well as an improved architecture with additional output filtering.

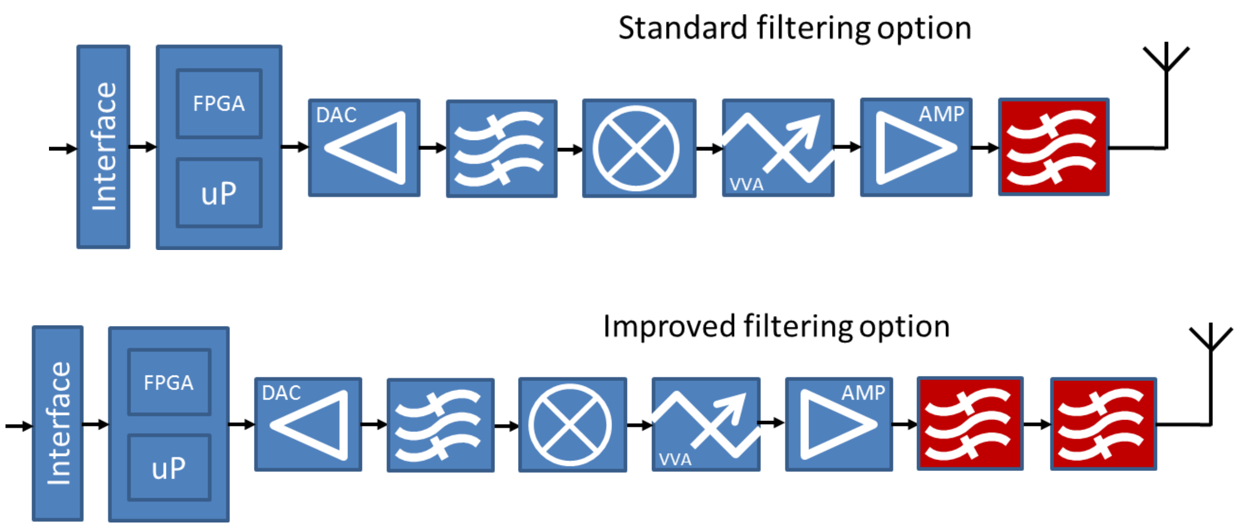


Figure 23 Transmitter architecture (3) – bandpass IF DAC with Mixer upconvertor

5.4.2 Stakeholder feedback

5.22 We approached two base station vendors and one Radio Frequency (RF) chipset vendor with a detailed list of our assumptions requiring confirmation and questions. Specifically, the following was asked:

- Out of the three presented transmitter architectures, which one was used?
- Is our noise modelling approach correct?
- What is the noise floor from a typical IQ modulator?
- Who are the RF chipset vendors?
- What output filter type and selectivity is typical used?
- What improvement to the output filter would be required to achieve -65dBm/MHz at 2700MHz?
- Which RF filter components are typically used and would serve as a reference for our study?

5.4.2.1 Access point vendor 1: Ubiquisys[1]

5.23 It was confirmed that transmitter architecture 1 is the industry standard for Home/ Local Area Base Station (LABS), and RF chipsets were available from Maxim, ADI, Lime Microsystems and Qualcomm.

5.24 It was stated that for 10-20dBm EIRP transmitters one RF filter was needed, and for 20-30dBm EIRP transmitters two RF filters would be required.

5.25 We were told that RF filters were available from Avago, Epcos and Murata.

[1] http://www.ubiquisys.com/

5.4.2.2 Access point vendor 2: Airwalk[2]

5.26 It was confirmed that transmitter architecture 1 is the industry standard for Home/LABS, and RF chipsets are available from Lime Microsystems (LMS6002), Qualcomm, Analog Devices and Maxim.

5.27 We were told that the RF duplex filter is currently a three pole design, and that meeting an unwanted emission level of -65dBm/MHz may require five poles. It was estimated that 10-15dB more rejection required was given.

5.28 Some discussions took place regarding the placement of the additional filtering. We were told that due to RF chipset integration, it was not possible to access the IQ modulator output directly to place an RF filter, and that the only place an additional filter could be placed is before or after the PA device.

5.4.2.3 RF chipset supplier: Lime Microsystems[3]

5.29 It was confirmed that transmitter architecture (1) is the industry standard for Home/LABS

5.30 We were told the IQ noise floor was dominated by the Phase Locked Loop (PLL) or frequency generator phase noise.

5.31 Real Wireless stated they had found the ADI ADF4602 RF chipset datasheet [14] in the public domain and asked whether it had typical noise performance. It was confirmed that this part is typical of a Universal Mobile Telecommunications System (UMTS) part in terms of noise performance, and that as LTE Band 7 was higher in frequency than UMTS, an RF chipset for LTE Band 7 noise performance would be a few decibels worse.

5.4.3 Duplexer filter selectivity

5.32 A review of LTE FDD transmitBand 7 (2620-2690MHz) duplexer filters was carried out. Additionally UMTS and PCS filters were examined to appreciate the level of selectivity that can typically be achieved. The example plot shown in Figure 24 uses a response similar to the ACMD-6007 handset duplexer from Avago Technologies [15] which was found in the public domain. It is assumed here that a typical duplex filter gives zero relative attenuation at 2615MHz on the lower side and at 2700MHz on the upper side. This filter selectivity was used in this study.

5.33 Some additional selectivity (e.g. 10-15dB) may be possible from a non-standard uprated 2620-2690MHz passband filter at 2700MHz; however this would be at the expense of increased insertion loss (not helpful after the PA device), and increased number of poles and therefore increased size and cost, so we have not relied on an assumption of this additional selectivity.

[2] http://www.airwalkcom.com/
[3] http://www.limemicro.com/

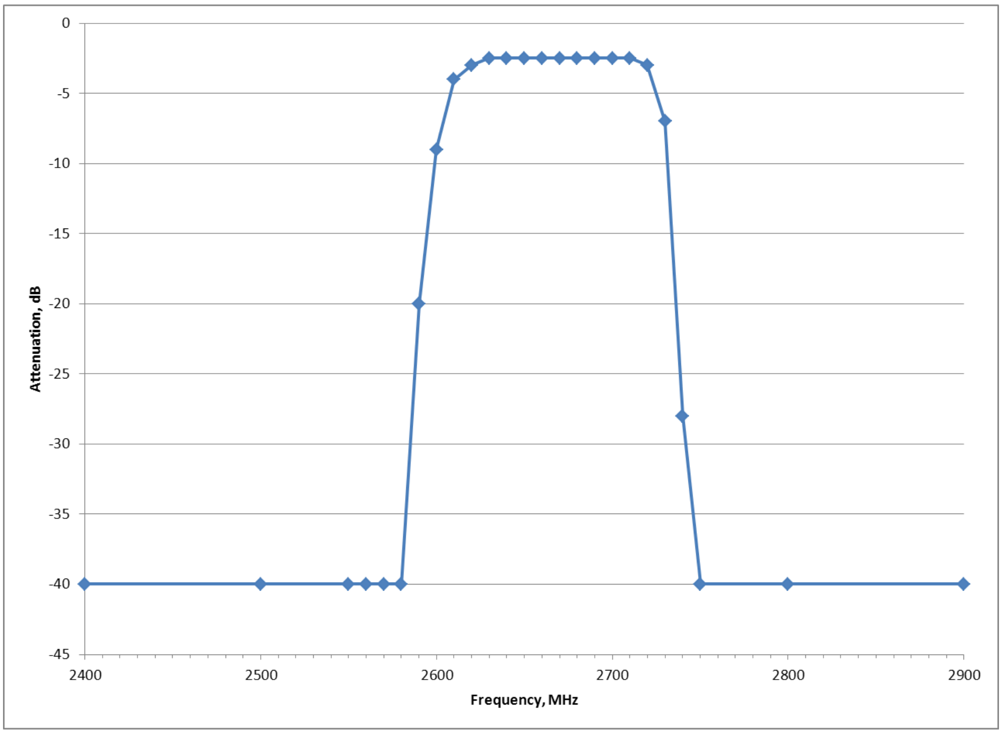


Figure 24 Transmit output filter used in typical unmodified access point

5.4.4 Spectral regrowth modelling

5.34 Spectral regrowth in caused when a waveform of non-constant envelope passes through a non-linear device. There are many ways to model this non-linearity including fitting a polynomial to measured data and power amplifier look-up tables with interpolation. Other models account for the memory effects in the non-linear device and there are various approaches to modelling this. Some models are primarily cubic in response and others include 5th and 7th order effects too. Some simple models account of amplitude non-linear effects whilst most also account for phase non-linear effects.

5.35 For the purpose of this study, after a review of the models, the Ghobani model [16] was chosen as it is representative of field effect transistor solid state power amplifiers, and includes amplitude and phase distortion as well as being rich in higher odd order polynomial coefficients. This model, implemented in Simulink [17], contains polynomial coefficients derived to match to real measured data. The block allows the modeller to adjust the drive level of the model in order to adjust the ACLR. The drive level in the model was adjusted to give an ACLR of 45dB as set out in the 3GPP standards.

5.36 In order to determine how the spectral regrowth rolls off with frequency offset from the carrier, a simple Orthogonal Frequency-Division Multiplexing (OFDM) waveform was generated using the model shown in Figure 25.

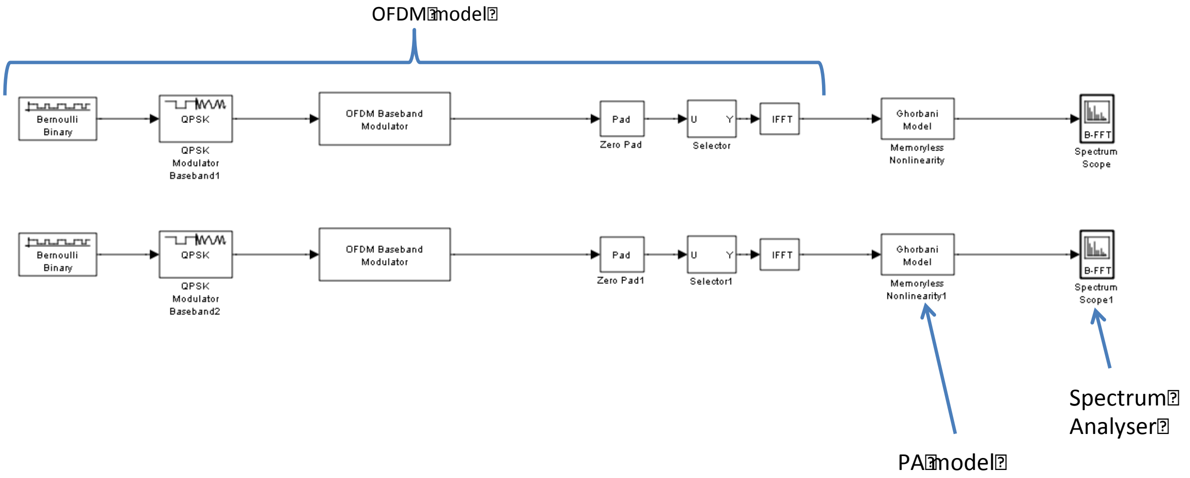


Figure 25 Simple OFDM generator and non-linear models

5.37 The signal was passed through the non-linear device modelled by the Ghorbani equations as follows:

PA output : y(t) = A(r(t))cos{ω0t+Ψ(t)+Φ(r(t))}

where A(r) = x1rx2/(1+x3rx2) + x4r

and Φ(r) = y1ry2/(1+y3ry2) + y4r

5.38 The parameters in these equations are defined as follows:

- y(t) is the time domain voltage at the power amplifier output
- r(t) is the time domain voltage at the power amplifier input
- A(r) is the amplitude modulation of the input voltage waveform as a function of input voltage envelope level
- Φ(r) is the phase modulation of the input voltage waveform as a function of input voltage envelope level

5.39 The parameters x1-x4 and y1-y4 are constants used in the amplitude and phase modulation equations, which have been found empirically by curve fitting to measured data. The values of these parameters as characterised by Ghorbani are:

x_1 = 8.1081 y1 = 4.6645

x2 = 1.5413 y2 = 2.0965

x3 = 6.5202 y3 = 10.88

x4 = -0.0718 y4 = -0.003

5.40 After matching the ACLR level to 45dB, the resultant spectral regrowth used in the study was a 20dB roll-off over 10MHz for the 10MHz channels, and a 10dB roll-off over 10MHz for the 20MHz channels.

5.41 Figure 26 and Figure 27 show example outputs from this model for 10 MHz and 20 MHz waveforms respectively.

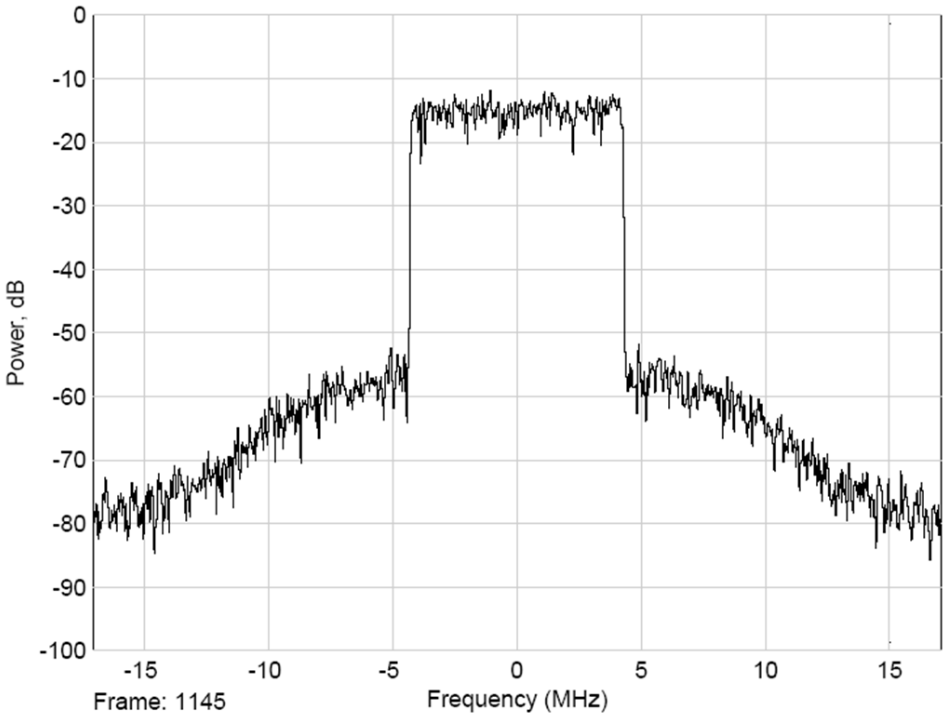


Figure 26 Plot showing simulated spectral regrowth from a 10MHz OFDM waveform

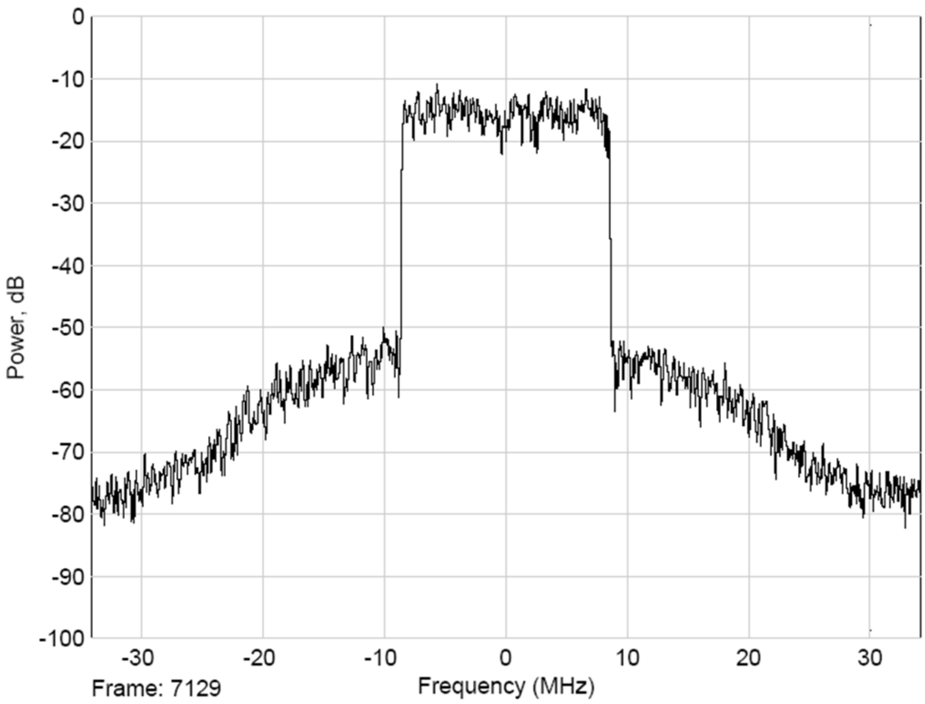


Figure 27 Plot showing simulated spectral regrowth from a 20MHz OFDM waveform

5.4.5 Transmit noise emissions calculations

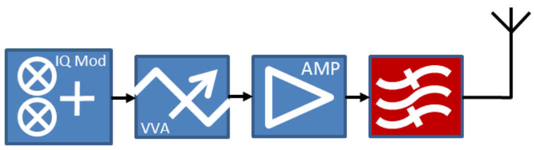
5.42 In order to model the noise at the transmitter output, the following equations were used. The noise power comprises three parts:

(a) the IQ modulator noise floor increased by the following gain and reduced by the filtering,

(b) thermal noise with power spectral density kT (i.e. -174dBm/Hz) increased by the following gain, transmit noise figure and reduced by the filtering, and

(c) the PA spectral regrowth reduced by the filtering, modelled using the model described earlier.

All terms are defined below.



$$P_{noise}(W/Hz) = IQ_{noise}(f).G_{tx}.G_{filter}(f) + k.T.F_{tx}.G_{tx}.G_{filter}(f) + PA_{regrowth}(f).G_{filter}(f)$$

$$P_{noise}(W/MHz) = P_{noise}(W/Hz) . 1e6$$

where the parameters are defined as follows:

- $IQ_{noise}(f)$ = noise from the IQ modulator mostly caused by the PLL frequency synthesiser phase noise. As previously learnt from our stakeholder discussions, the ADI ADF4602 [14] has a representative noise floor with levels of -165dBm/Hz at 40MHz offset and -171dBm/Hz at 80MHz offset. Other offset noise powers were obtained from the PLL phase noise plot on the datasheet. A level of -10dBm average output power was used as suggested in the chipset datasheet.

- G_{tx} = the gain from the output of the IQ modulator to the antenna EIRP point
- $G_{filter}(f)$ = the gain of the filter at various frequency offsets (i.e. filter selectivity)
- k = Boltzmann's constant (~1.38 x 10^{-23} J/K)
- T = Temperature in Kelvin, 290K used.
- F_{tx} = Noise Factor of the transmit chain from IQ modulator output to antenna eirp point
- $PA_{regrowth}(f)$ = the noise created in the PA causing spectral regrowth in adjacent and alternate channels.

5.4.6 Design of practical additional transmit filter

5.43 In order to estimate the selectivity of an additional filter used to decrease the noise emissions, a practical 3 pole ceramic resonator design was performed using the Coaxial Resonator Filter Tool (CRaFT) [18].

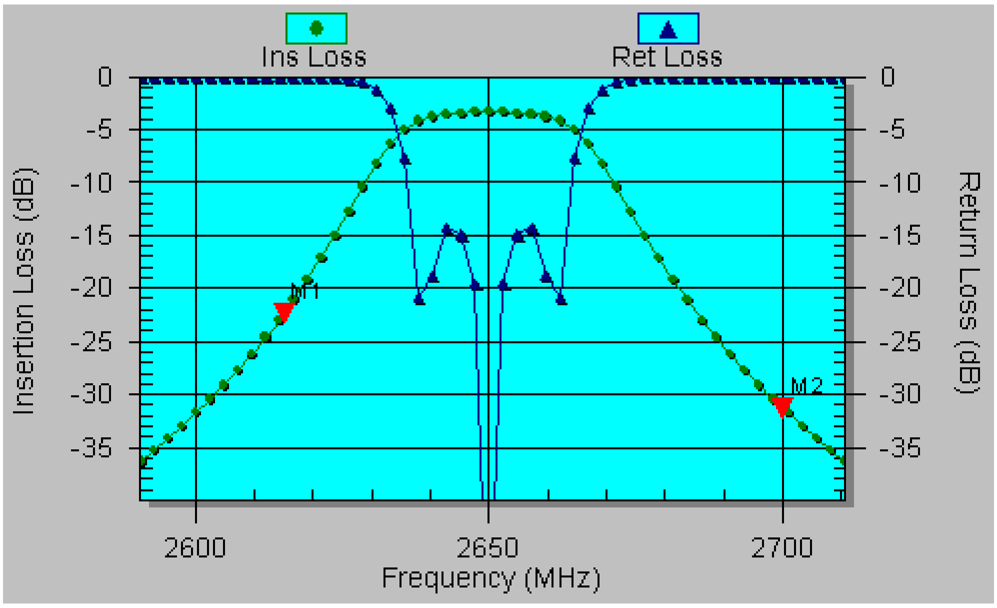


Figure 28 3 pole ceramic resonator filter for 10MHz channels

5.44 The design for the 10MHz channels gave an insertion loss of ~3dB,attenuation at 2615MHz = 16dBc and attenuation at 2700MHz = 25dBc.

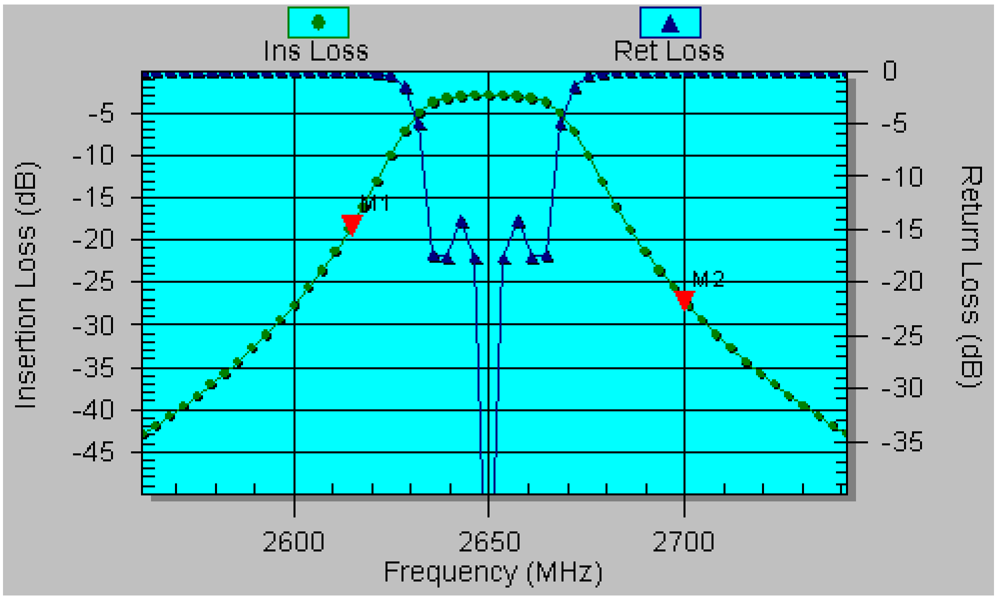


Figure 29 3 pole ceramic resonator filter for 20MHz channels

5.45 The design for the 20MHz channels gave an insertion loss of ~3dB, attenuation at 2615MHz = 12dBc and attenuation at 2700MHz = 21dBc.

5.46 The size of the practical filter can also be obtained from the CRaFT software tool:

Figure 30 Typical size of filter (dimensions in mm)

5.47 Whilst high-Q cavity filters could clearly give much higher selectivity, these were ruled out for a Home BS or LABS due to increased size and cost. These filters are used in macrocells.

5.48 It should also be noted that this additional filter is in cascade with the duplexer filter. The vendor may wish to combine the two in a higher order duplexer filter.

5.5 Calculation process

5.49 The noise calculated using the model in Section 5.4.5 was added to the spectral regrowth noise calculated from the PA model in Section 5.4.4. The combined noise was reduced by the duplex filter in Section 5.4.3 in the case of a typical unmodified base station design and by both the duplex filter and additional filter in Section 5.4.6 cascaded for the case of a modified base station.

5.50 The results were all calculated for architecture (1) for an EIRP of 30dBm. For both the typical unmodified and modified access points and for both 10MHz and 20MHz channels, the noise power versus frequency was plotted for each channel centre frequency case.

5.51 The final set of graphs show the maximum EIRP possible as a function of channel centre frequency to achieve unwanted emission levels below (a) -65dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz, and (b) -45dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz. In this case, the noise power from the model is reduced 1:1 with the output EIRP power. This is valid over the range of interest as the IQ modulator noise is dominated by the gain between the IQ modulator and the antenna EIRP, and for the case of the PA spectral regrowth it is assumed that the vendor will select a PA device meeting the 3GPP ACLR mask for each output EIRP in order to save cost. So, a PA device selected for a home access point with 20dBm EIRP will produce the same ACLR as a local area access point with 30dBm EIRP in this modelling approach used.

5.6 Results

5.52 The results in Section 5.6.1 show the noise power in dBm/MHz as a function of frequency in MHz for a typical unmodified access point. The first two plots Figure 31 and Figure 32 show this for 10MHz channels centred on various channel frequencies, outlined in the legend. Figure 31 shows the noise emissions above the channel centre frequency and Figure 32 shows the noise emissions below the channel centre frequency. The second two plots Figure 33 and Figure 34 repeat this procedure for 20MHz channels, also outlined in the legend.

5.53 The results in Section 5.6.2 show the noise power in dBm/MHz as a function of frequency in MHz for a modified access point with improved output RF filtering. The first two plots Figure 35 and Figure 36 show this for 10MHz channels centred on various channel frequencies, outlined in the legend. Figure 35 shows the noise emissions above the channel centre frequency and Figure 36 shows the noise emissions below the channel centre frequency. The second two plots Figure 37 and Figure 38 repeat this procedure for 20MHz channels, also outlined in the legend.

5.54 The results in Section 5.6.3 show the maximum possible transmit EIRP as a function of channel centre frequency in order to achieve unwanted emission levels below (a) -65dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz, and (b) -45dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz. The first two plots Figure 39 and Figure 40 for 10MHz and 20MHz channels, presents these findings for a typical unmodified access point. The second two plots Figure 41 and Figure 42 for 10MHz and 20MHz channels respectively, present these findings for a modified access point with improved output RF filtering.

5.6.1 Typical unmodified access point noise emissions

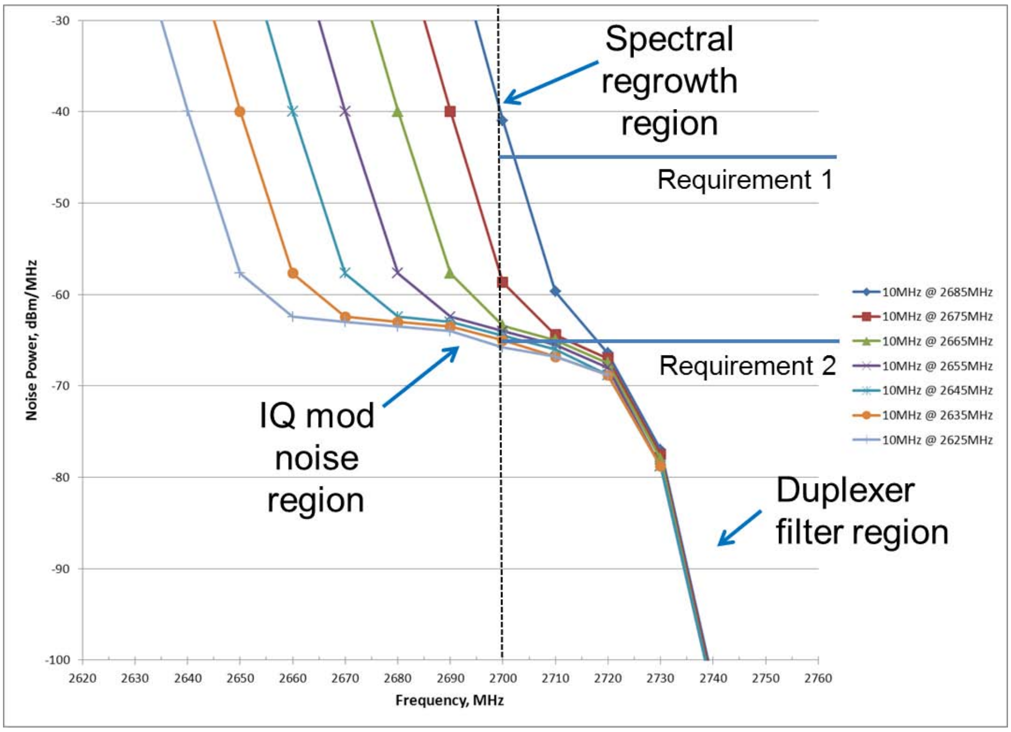


Figure 31 Architecture (1), 30dBm EIRP, 10MHz Channels, Upper Side

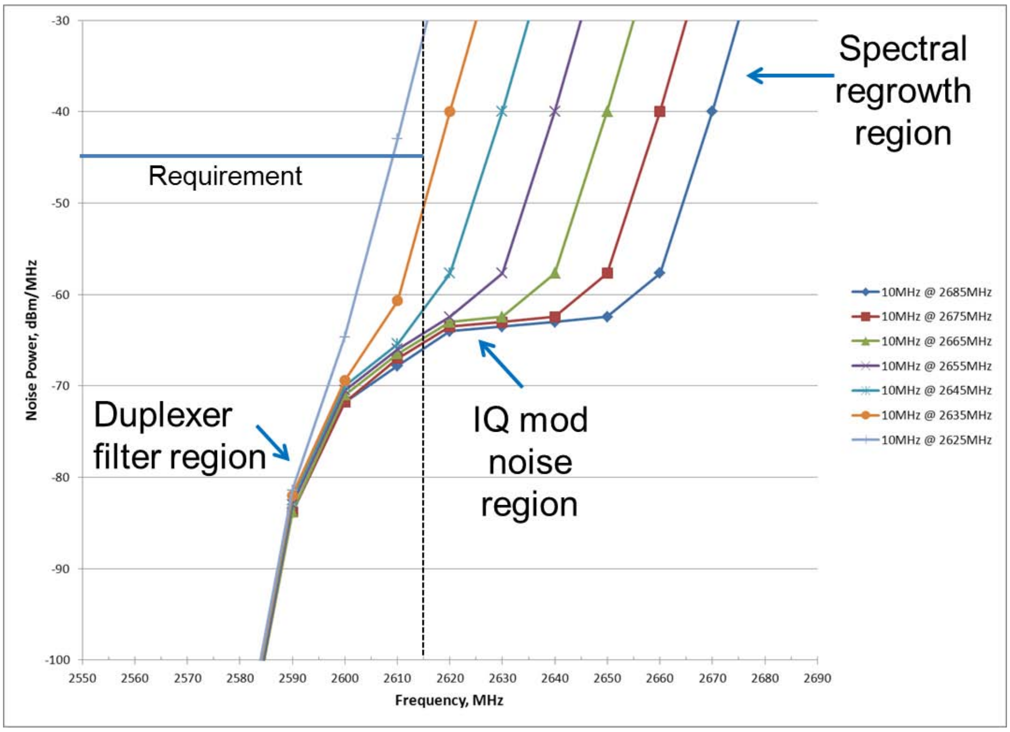


Figure 32 Architecture (1), 30dBm EIRP, 10MHz Channels, Lower Side

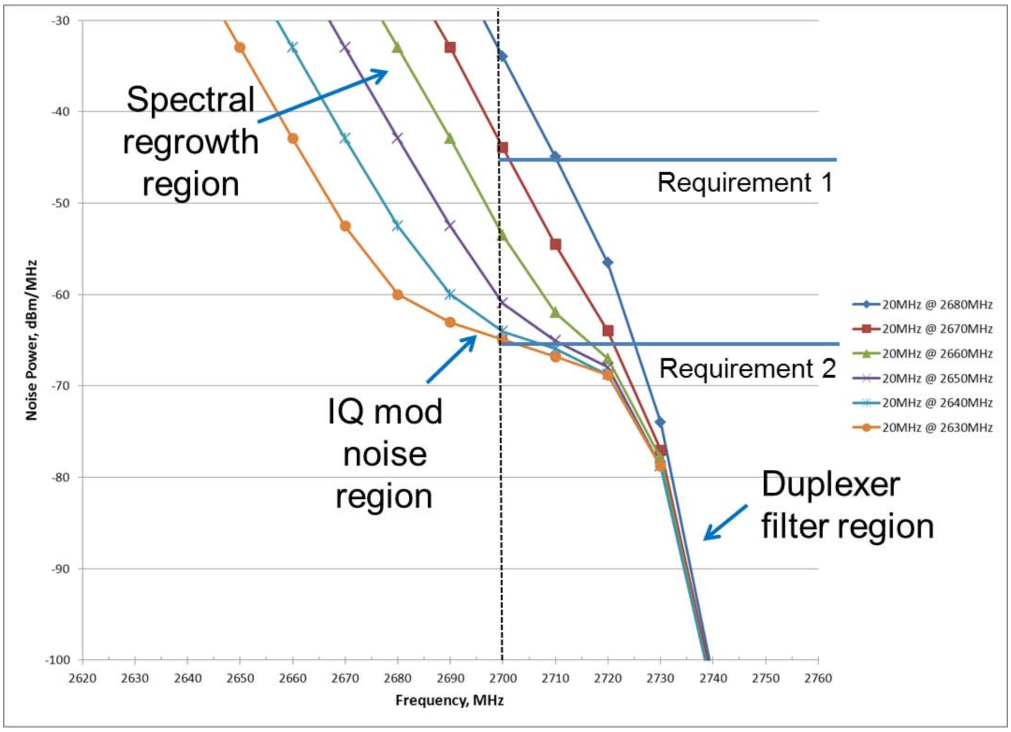


Figure 33 Architecture (1), 30dBm EIRP, 20MHz Channels, Upper Side

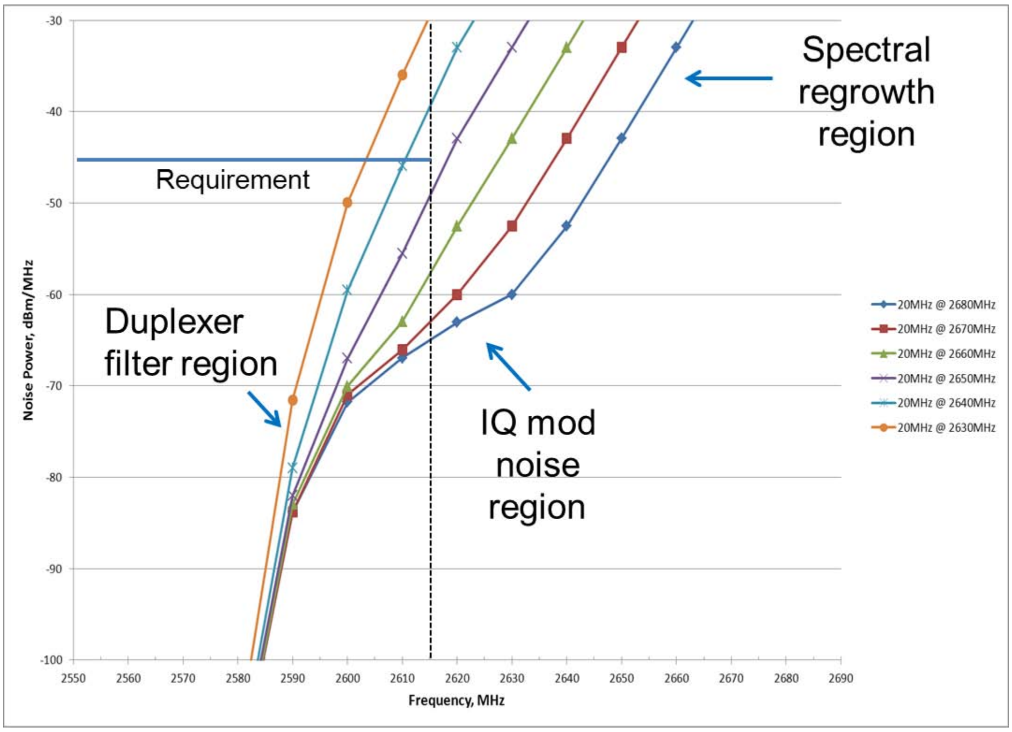


Figure 34 Architecture (1), 30dBm EIRP, 20MHz Channels, Lower Side

5.6.2 Modified access point noise emissions

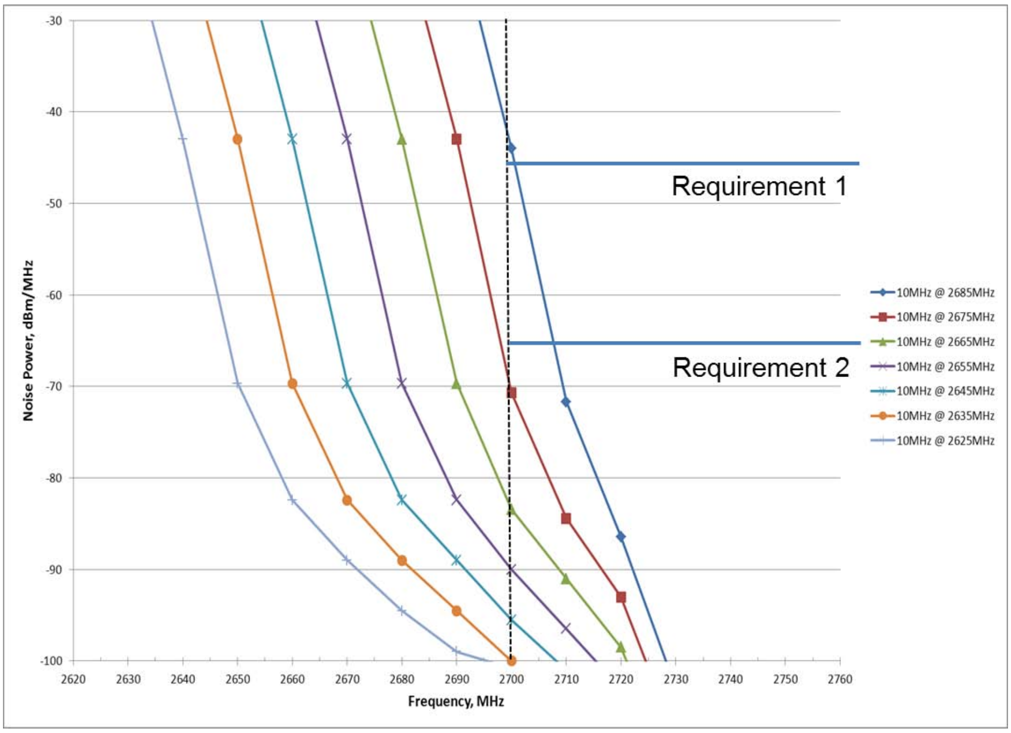


Figure 35 Architecture (1), 30dBm EIRP, 10MHz Channels, Upper Side

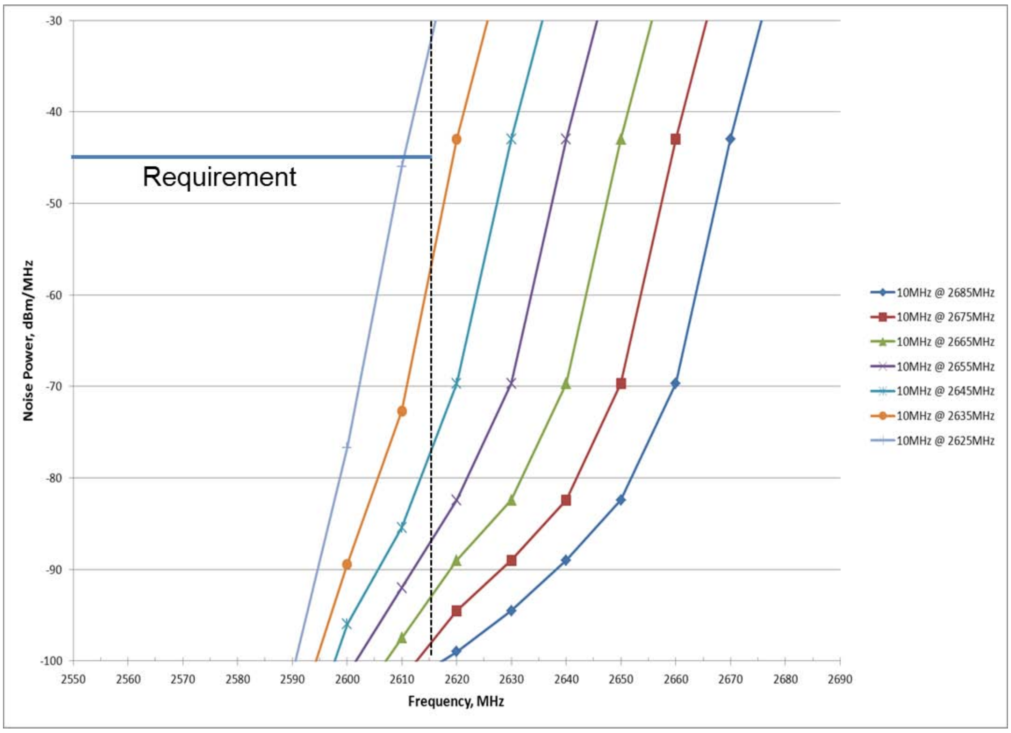


Figure 36 Architecture (1), 30dBm EIRP, 10MHz Channels, Lower Side

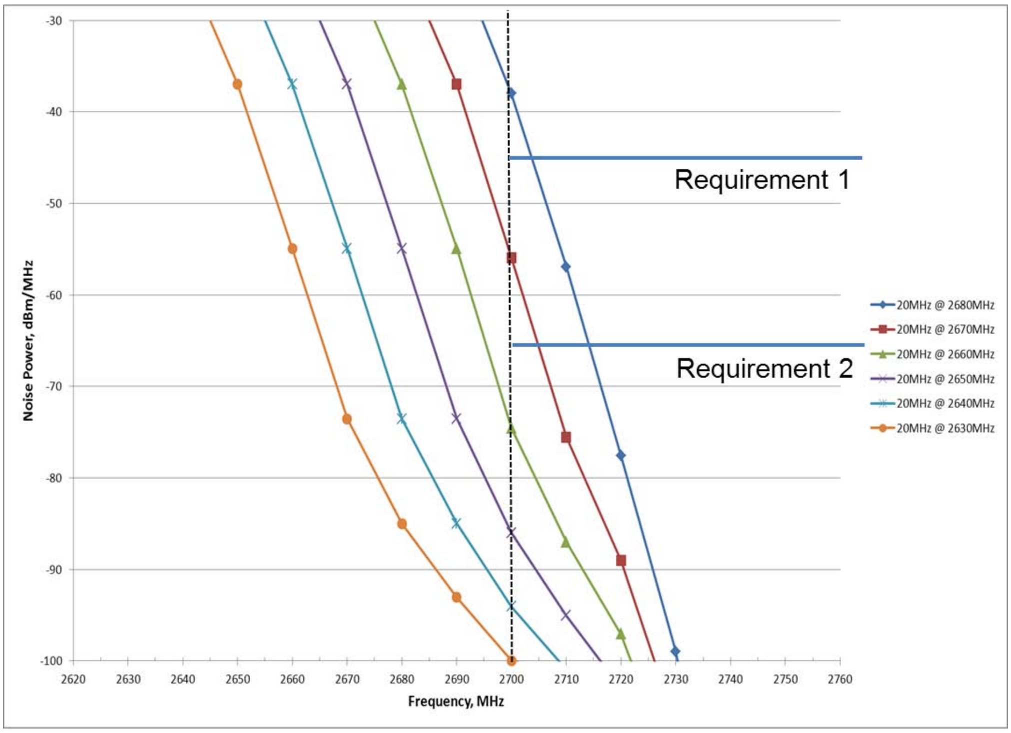


Figure 37 Architecture (1), 30dBm EIRP, 20MHz Channels, Upper Side

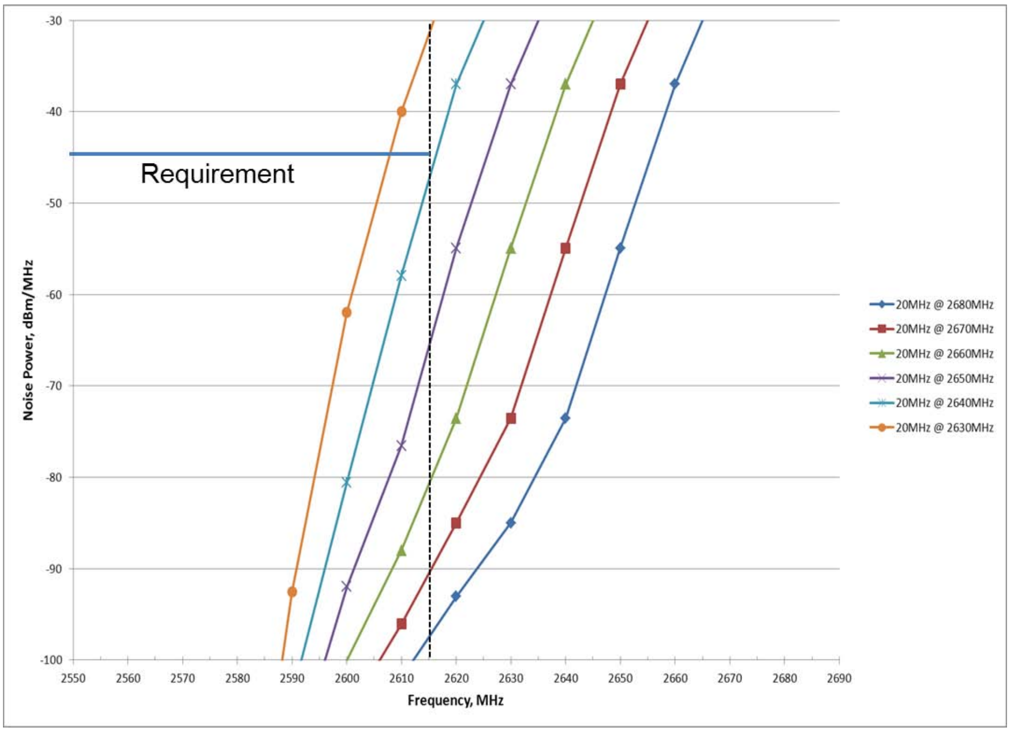


Figure 38 Architecture (1), 30dBm EIRP, 20MHz Channels, Lower Side

5.6.3 Maximum EIRP versus channel frequency

5.6.3.1 Unmodified access point

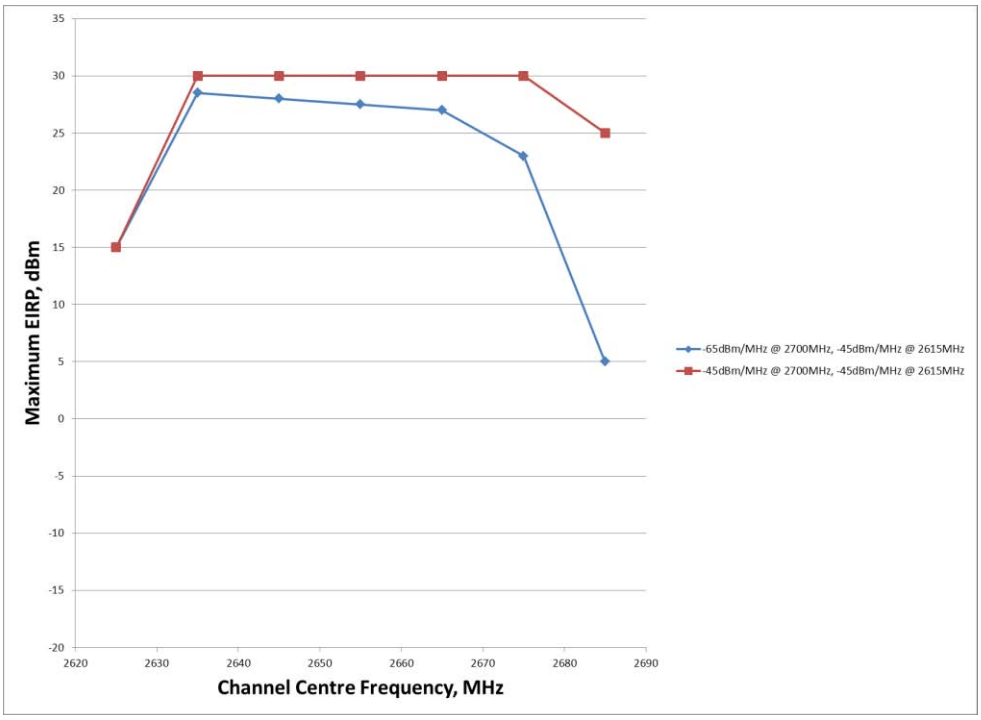


Figure 39 Maximum EIRP without Channel Filter - Architecture (1), 10MHz Channels

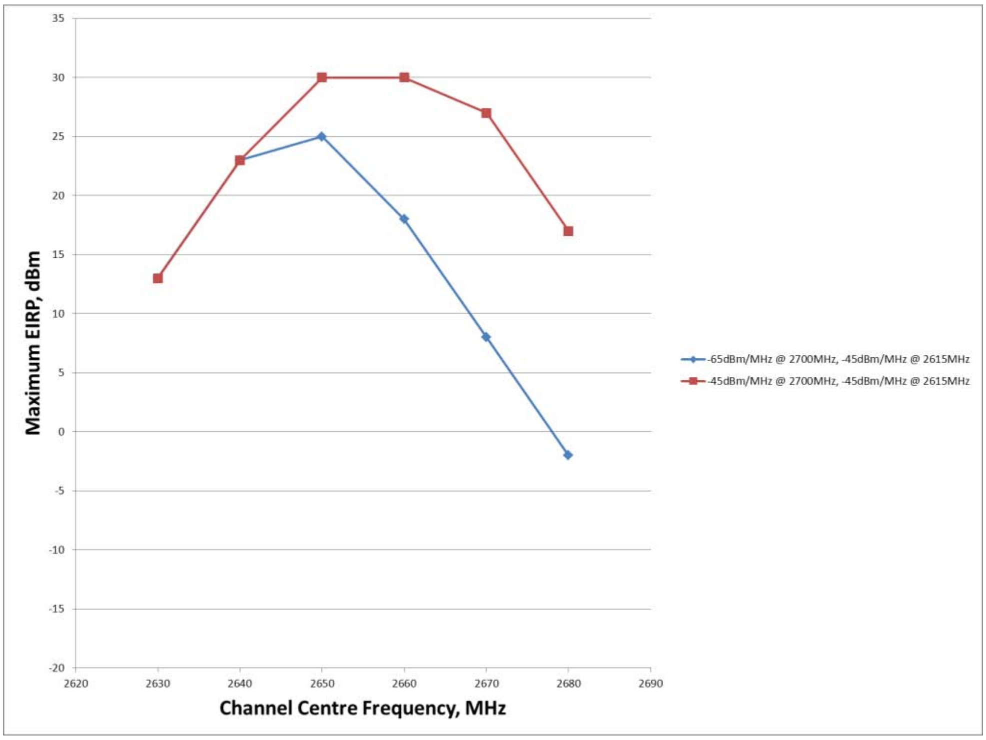


Figure 40 Maximum EIRP without Channel Filter - Architecture (1), 20MHz Channels

5.6.3.2 Modified access point

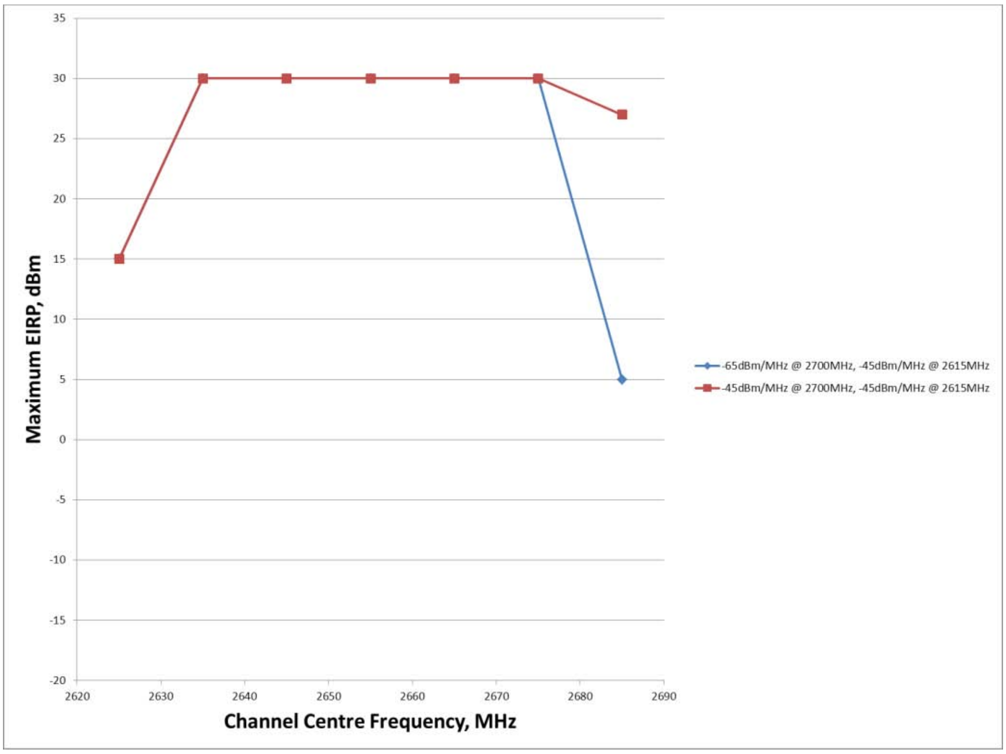


Figure 41 Maximum EIRP with Channel Filter - Architecture (1), 10MHz Channels

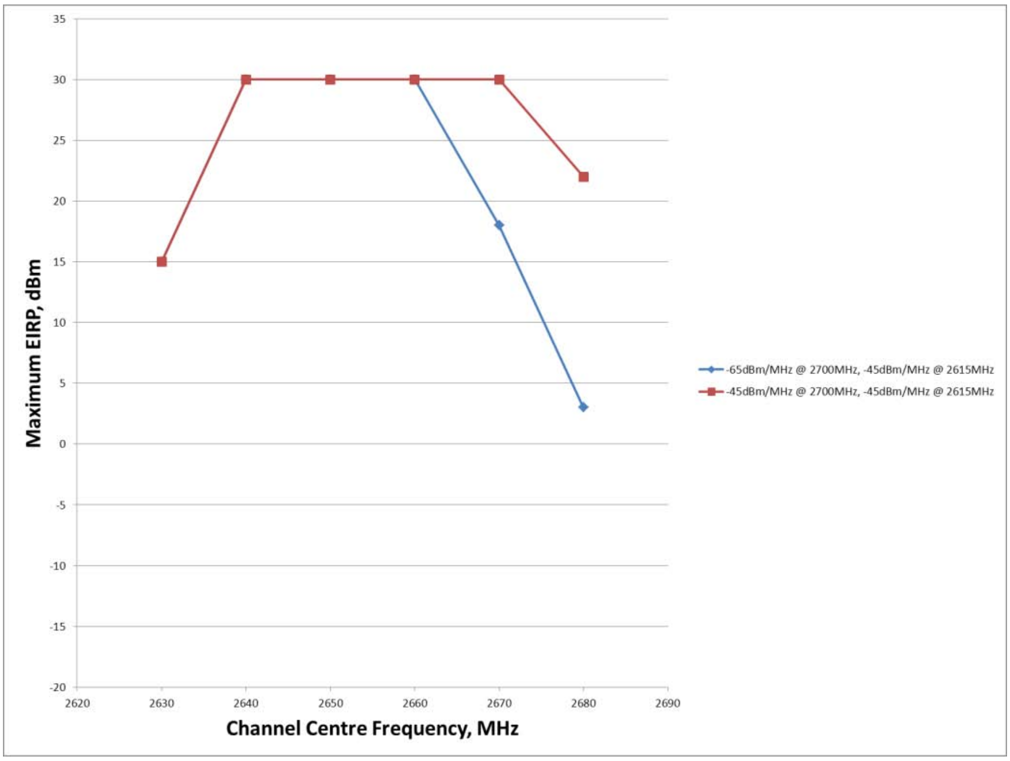


Figure 42 Maximum EIRP with Channel Filter - Architecture (1), 20MHz Channels

5.7 Findings

5.55 For the typical unmodified access point noise emissions plots in Section 5.6.1 there exists three regions. Close to the channel centre frequency is the region where the power amplifier spectral regrowth emission dominates the noise. As the frequency offset from the channel centre frequency is increased, the spectral regrowth falls-off to reveal the noise floor generated by the multiplied up IQ modulator noise. This noise region gradually tapers off with increasing offset to the point where the RF output filtering begins to take effect.

5.56 For the modified access point noise emissions plots in Section 5.6.2, where a channelized filter is used, the spectral regrowth and output RF filtering dominates the results. The channelized filter cuts in before the IQ modulator noise region begins, and therefore this region is greatly attenuated.

5.57 The main results from this study are shown in Section 5.6.3. Two unwanted emission levels are considered, (a) -65dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz, and (b) -45dBm/MHz at 2700MHz and -45dBm/MHz at 2615MHz.

5.58 Figure 39 shows the maximum EIRP possible for an unmodified access point with 10MHz channels. It clearly shows that if unwanted emissions are to be kept below the levels outlined in (a), then 30dBm EIRP cannot be transmitted on either channel centre frequency, and that a maximum EIRP of 28dBm can be transmitted on a channel centred on 2635MHz. In the case when the unwanted emissions are to be kept below the levels outlined in (b), then 30dBm EIRP is available on all channels centred between 2635MHz and 2675MHz.

5.59 Figure 40 shows the maximum EIRP possible for an unmodified access point with 20MHz channels. It clearly shows that if the unwanted emissions are to be kept below the levels outlined in (a), then 30dBm EIRP cannot be transmitted on either channel centre frequency, and that a maximum EIRP of 25dBm can be transmitted on a channel centred on 2650MHz. In the case when the unwanted emissions are to be kept below the levels outlined in (b), then 30dBm EIRP is available on all channels centred between 2650MHz and 2660MHz.

5.60 Figure 41 shows the maximum EIRP possible for a modified access point with 10MHz channels. It clearly shows that if the unwanted emissions are to be kept below the levels outlined in (a), then 30dBm EIRP is available on all channels centred between 2635MHz and 2675MHz. In the case when the unwanted emissions are to be kept below the levels outlined in (b), then 30dBm EIRP is also available on all channels centred between 2635MHz and 2675MHz.

5.61 Figure 42 shows the maximum EIRP possible for a modified access point with 20MHz channels. It clearly shows that if the unwanted emissions are to be kept below the levels outlined in (a), then 30dBm EIRP is available on all channels centred between 2640MHz and 2660MHz. In the case when the unwanted emissions are to be kept below the levels outlined in (b), then 30dBm EIRP is available on all channels centred between 2640MHz and 2670MHz.

5.8 Recommendations

5.62 These recommendations assume that Ofcom licenses a maximum EIRP of 30dBm for Home and Local Area BS in UK.

5.63 For 10MHz channels, needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

5.64 For 10MHz channels needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2635MHz and 2675MHz.

5.65 For 20MHz channels needing to meet an unwanted emission level of -65dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2660MHz. However, this may mean the vendor requires a reduction in EIRP below 30dBm and/or additional RF filtering to meet this unwanted emissions level.

5.66 For 20MHz channels needing to meet an unwanted emission level of -45dBm/MHz at 2700MHz, low-power access points could potentially be deployed in any channel centre frequency between 2640MHz and 2670MHz. This may mean the vendor requires additional RF filtering to meet this unwanted emissions level.

5.67 Using these recommended frequency ranges, the implication on access point vendors is likely to be:

- For BS using 10MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after Power Amplifier (PA) device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS
- For BS using 10MHz channels, having to meet an unwanted emissions level of -45dBm/MHz:
    - For 30 dBm EIRP, vendors can probably use an unmodified but well-designed BS
    - For 27 dBm EIRP, vendors can probably use an unmodified but well-designed BS
    - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS
- For BS using 20MHz channels, having to meet an unwanted emissions level of -65dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 20 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
- For BS using 20MHz channels, having to meet an unwanted emissions level of -45dBm/MHz:
    - For 30 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter
    - For 27 dBm EIRP, vendor may need to use additional bandpass filter after PA device or improved duplexer filter

  - For 20 dBm EIRP, vendors can probably use an unmodified but well-designed BS.

5.9 Answers to study questions

Study Questions	Answers to Study Questions
In association with protection of radar, analyse the feasibility of low-power access points meeting additional block-edge mask limits of (a) -65dBm/MHz EIRP and (b) -45dBm/MHz EIRP above 2700 MHz. Either of the limits may apply, depending on circumstances. We need a view on the impact of assigning spectrum for low-power access points at different frequencies within the 2620 to 2690 MHz band instead of the uppermost block:	Graphs have been supplied that show maximum EIRP possible at each channel frequency for both unwanted emissions levels. The findings from this study are given in Section 5.7. It should be noted that the uppermost and lowermost channels should be avoided as these place increased burdens and costs on the access point vendors.
Assume the low-power access points are using 10 MHz LTE and 20 MHz LTE	Both 10MHz and 20MHz channels have been analysed.
Include the full range of access points from the low-power LTE study, i.e. residential, office, indoor/outdoor public space, and business park/campus	Graphs have been provided for a wide range of possible EIRP levels up to 30dBm.
Include as an assumption that the access points will be unmodified units, i.e. standard units placed on the European market, meeting the requirements of the 3GPP standards. Make reasonable assumptions about the performance of the units and unwanted emissions into spectrum outside the 2620 to 2690 MHz operating band, as well as antenna gain. Make reasonable assumptions about any additional filtering that could be included as an installation measure for particular categories of low-power access point	The analysis has been carried out for typical unmodified units as well units with improved output filtering. Practical cost-effective filter performance and dimensions have been provided.
At what position in frequency would we need to place the low-power block in order to have a reasonable expectation that emissions from low-power units above 2700 MHz would be below the limits of (a) -65dBm/MHz EIRP and (b) -45dBm/MHz EIRP?	The optimum centre frequency for the licence, as a function of channel bandwidth, noise emission requirements, presence of additional filtering and EIRP can be found easily by inspecting the graphs in Section 5.6.3
Bear in mind that access points would also need to meet the baseline requirement from Commission Decision 2008/477/EC that out-of-block emissions do not exceed -45dBm/MHz EIRP in frequencies below 2615 MHz.	This additional requirement is accounted for in the analysis.
Based on the outcome of this study, make recommendations about the minimum frequency separation between the low-power block and the radar band.	The minimum frequency separation is a function of channel bandwidth, noise emission requirements, presence of additional filtering and EIRP. Recommendations are given in Section 5.8.

5.10 Optimal placement of the low-power block within the 2.6GHz band

5.68 The results above can now finally be used to define the optimal channels and are as follows:

Emission level above 2700MHz	Low power block bandwidth	Optimal channel centre frequency
-65dBm/MHz EIRP	10 MHz	2635 MHz
	20 MHz	2650 MHz
-45dBm/MHz EIRP	10 MHz	2635 to 2675 MHz
	20 MHz	2650 to 2660 MHz

Table 10 Optimal placement of the low-power block

5.69 Even at these channel centre frequencies, in order to meet an unwanted emissions level above 2700MHz of -65 dBm/MHz EIRP, it is likely that the operator would need to reduce the output power EIRP to 28dBm and 25dBm in the 10MHz and 20MHz channel bandwidth cases respectively or use a modified access point with higher selectivity output filter, in order to meet this unwanted emissions level.

5.70 At these channel centre frequencies, in order to meet the proposed regulatory limit on unwanted emissions above 2700MHz of -45 dBm/MHz EIRP, it is likely that the operator could use an unmodified access point at the full 30dBm EIRP power level.

6 C: Hybrid approach to shared spectrum

6.1 Ofcom would like to determine technical licence conditions to allow standard power and low power licensees to share spectrum in a hybrid configuration

6.1 One option for placement of the low power block is partially overlapping a standard power block, allowing both to have access to 2 x 20 MHz in places where mutual interference is low and thereby to maximise the available data rates (assuming Long Term Evolution (LTE) technology) or the number of operators who can operate in the same area in the case of low power licensees. When interference does occur, however, it is important that the restrictions which apply are clear to all licensees and effective in limiting service degradation. Ofcom has requested that the specific form of such restrictions be analysed under the assumption for this study that the standard power licensee takes precedence over the low-power licensees in the shared block.

6.2 Study questions

6.2 Analyse the potential impact on a standard-power operator who shares access to 10 MHz of spectrum with low-power operators.

- Assume that the standard-power operator has a block of 20 MHz, where 10 MHz is not shared and in the other 10 MHz low-power operators are permitted
- Assume the low-power operators have access to 20 MHz in total: 10 MHz spectrum for low-power only and 10 MHz spectrum as an underlay to a 20 MHz standard-power licence. The standard-power operator has priority in the shared 10 MHz

6.3 Include the following scenarios:

a) Impact of “hole-punching” in the standard-power network coverage due to downlink interference. Since this is more likely to occur in low signal conditions, how can low-power access points be sufficiently certain that they will be able to avoid causing this problem?

b) Impact of base station receiver blocking on the standard power network, caused by terminals attached to a low-power access point.

c) Identify other relevant scenarios and agree them with Ofcom.

6.4 Determine the feasibility of underlay networks protecting standard-power use and providing sufficient confidence that existence of standard-power coverage will be detected and that procedures will be available to cease transmission in the underlay spectrum.

6.5 Assess whether information sharing between the low-power and standard-power operators will be an essential component of managing the hybrid approach.

6.3 Overview

6.6 Figure 43 gives an overview of the co-existence scenario in the hybrid approach. Both Standard Power (SP) and Low Power (LP) base stations may be deployed such that they have overlapping coverage. The networks comprise multiple Base Stations (BS) and user terminal devices (known as

User Equipments (UE) in 3GPP terminology. There will be a single standard power network and one or more low power networks. In this analysis, we are concerned with the protection of the standard power network from a low power network. We will consider situations where some form of information sharing amongst operators is relevant to this process, potentially via a shared database or via administrative means (Figure 43).

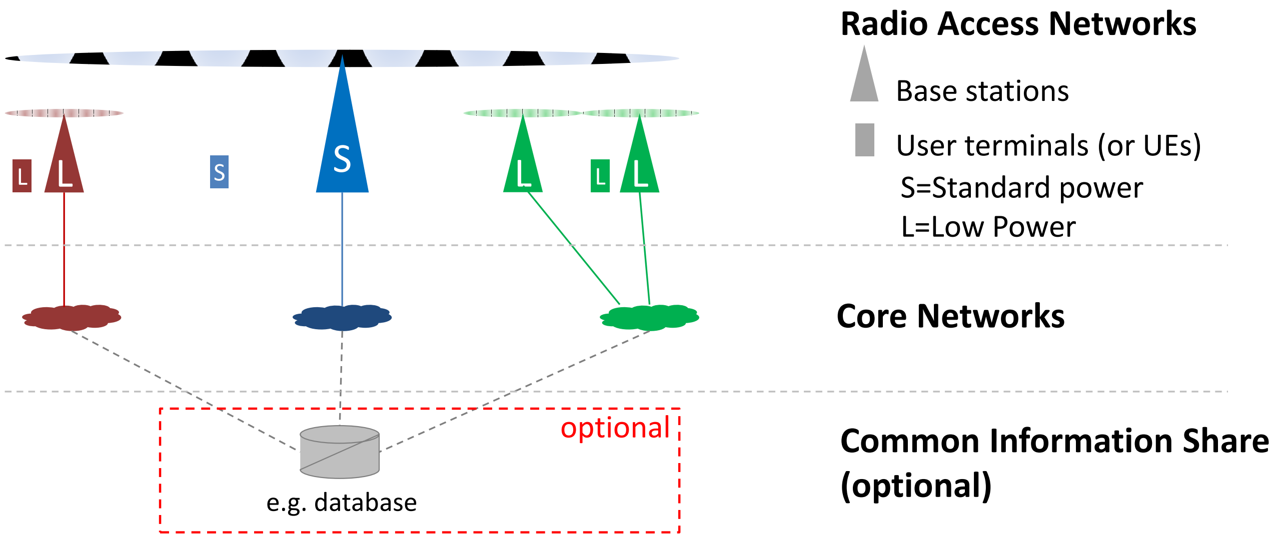


Figure 43 Overview of Co-existence scenario for Hybrid approach to shared spectrum

6.7 Figure 44 shows the channelisation plan for the hybrid approach. This represents either the uplink or downlink portions of a Frequency Division Duplex (FDD) scheme. The standard power network occupies 20MHz of spectrum over blocks a and b. The multiple low power shared access networks occupy 20MHz of spectrum over blocks b and c. Block b is 10MHz of overlap between the SP channel and the LP channel. It is the interference to the standard power network from low power UEs and BSs transmitting in block b that is the subject of this analysis.

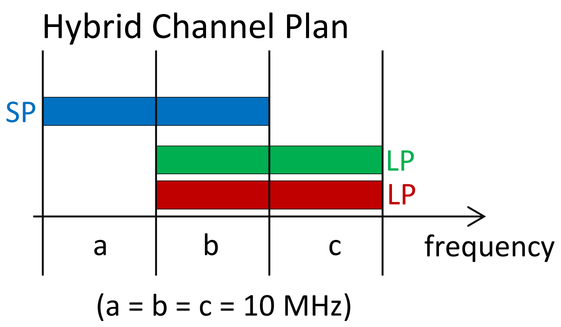


Figure 44 Channelization plan for Hybrid Approach to Shared Spectrum

6.8 The analyses of the downlink and uplink interference scenarios for the hybrid approach are quite different, and so are treated separately in the following sections. In each case, challenging interference scenarios are identified and the extent of interference is calculated. Interference co-ordination schemes to protect the standard power network are then proposed, and algorithms derived which could form the basis for co-ordination rules.

6.4 *Interference to the standard power downlink*

6.4.1 Challenging downlink scenario

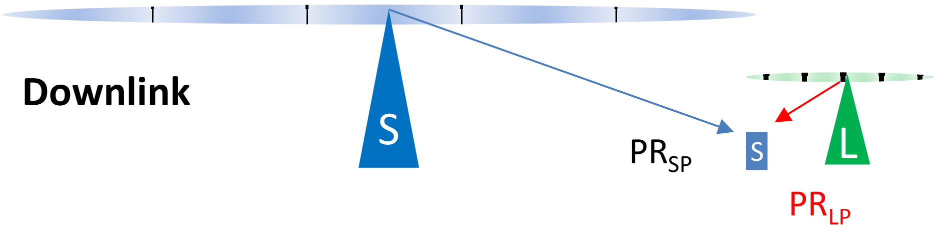


Figure 45 challenging scenario for interference to standard power downlink

6.9 Figure 45 shows the challenging case for the SP downlink: a UE connected to a Standard Power network (SPUE) is at the edge of its cell but close to a Low Power Base Station (LPBS). The wanted signal, PR_{SP}, is low, and the unwanted signal PR_{LP} is potentially high. When PR_{LP}>>PR_{SP}, the Carrier to Interference Ratio (CIR) for the SPUE is low, which can impact both user throughput and reception of control information. This condition will occur when the SPUE is in close proximity to the LPBS. The effect is to create an interference zone around the LPBS. This is also referred to as 'hole punching' the SPBS's downlink coverage.

6.10 As the SPUE approaches the LPBS, interference over the overlapping part of the hybrid channel will increase, causing a CIR degradation for parts of the Physical Downlink Shared Channel (PDSCH) for user data and Physical Downlink Control Channel (PDCCH).

6.11 Reducing CIR will reduce overall Signal to Interference plus Noise Ratio (SINR) and the PDSCH user data throughput will be reduced until a threshold SINR, SINRmin, is exceeded, below which zero throughput occurs. 3GPP provides an indicative value for SINRmin for the FDD LTE downlink as -10dB [9].

6.12 For a hybrid channel configuration, the Standard Power Base Station (SPBS) will detect low SINR on the overlapping resource blocks and schedule SPUEs in interference zones to use resources in the non-overlapping part of the hybrid channel. Thus interference to PDSCH can be mitigated where interference zone is a small proportion of the standard power cell area.

6.13 Control channels Packet Data Control Channel (PDCCH), Physical Control Format Indicator Channel (PFICH) and Physical Hybrid ARQ Indicator Channel (PHICH) are stated to require SINR>-1.7dB to function correctly [6]. SPUEs with downlink SINR < -1.7dB will not be able to correctly decode these control channels unless mitigation schemes such as time shifting are used to protect them. The analysis in work package D describes how this might be achieved. It is assumed that mitigation is in place to protect these control channels.

6.14 The Physical Broadcast Channel (PBCH) and synchronisation channels at the centre of the SP channel fall just beyond the furthest resource block of the LP channel. It is assumed that these are protected and SPUEs will be able to maintain synchronisation when in interference zones.

6.4.2 Method and Assumptions for the analysis

6.15 The overall method for analysing downlink interference and defining co-ordination rule is as follows:

1) Evaluate size of downlink interference zone as a function of LPBS range from the SPBS
2) Evaluate how LPBS measurement based power control can reduce size of interference zone
3) Define algorithm for co-ordination rule to give an acceptable level of interference over an acceptably sized zone

6.4.2.1 Assumptions

- **Path Loss models** have been selected for consistency across the low power study, as follows:
    - Outdoor Scenario
        - SPBS-SPUE and SPBS-LPBS (for 'network listen' measurement)
            - Cost 231 Hata SE21 [19]
                - UE height 1.5m
                - BS height 15m
                - frequency = 2600 MHz
        - LPBS-SPUE
            - COST 231 Walfisch-Ikegami [11]
            - Parameters as given in per the low power study report

    - Indoor scenario
        - SPBS-SPUE and SPBS-LPBS (for 'network listen' measurement)
            - Cost 231 SE21 Hata [19] + XS
            - where XS is 7dB at the exterior wall increasing linearly as a function of distance to 21.1dB at the centre of the building [4]
        - LPBS-SPUE
            - For indoor SPUEs: COST 231 MultiWall [20]
            - For outdoor SPUEs: COST 231 MultiWall [20] + COST 231 Line of Sight [20] for the outdoor component, as described in §4.3.3 of reference [3]
        - Indoor residential:
            - 16m building length, based on square building with 500m^2 floor area spread over two floors.
        - Indoor commercial:
            - 40m building length, based on square building with 3200m^2 floor area spread over two floors.
        - Both indoor scenarios are based on the larger building sizes compared to the range described in the Low Power Shared Access study [3]. Larger buildings have been chosen as this represents a worst case for standard power terminals inside the building.
    - Shadow fading
        - The zone size can vary significantly due to the effect of shadow fading on either the wanted signal from the SPBS or the interfering signal from the LPBS.
        - The modelling provides results for the median case. e.g. median zone size.
        - A margin could be added to account for a worst case scenario for any given range (e.g. 14dB for two independent shadow fades), but this would make the zone size look pessimistically large.
        - Shadowing of the wanted SPBS signal would have a similar impact to the increased median path loss at a slightly higher range. Where zone size is controlled using network listen (see later) this will not be an issue.

- Shadowing of the unwanted LPBS signal is desirable and will decrease zone size

The median path loss models for the various cases are compared in Figure 46.

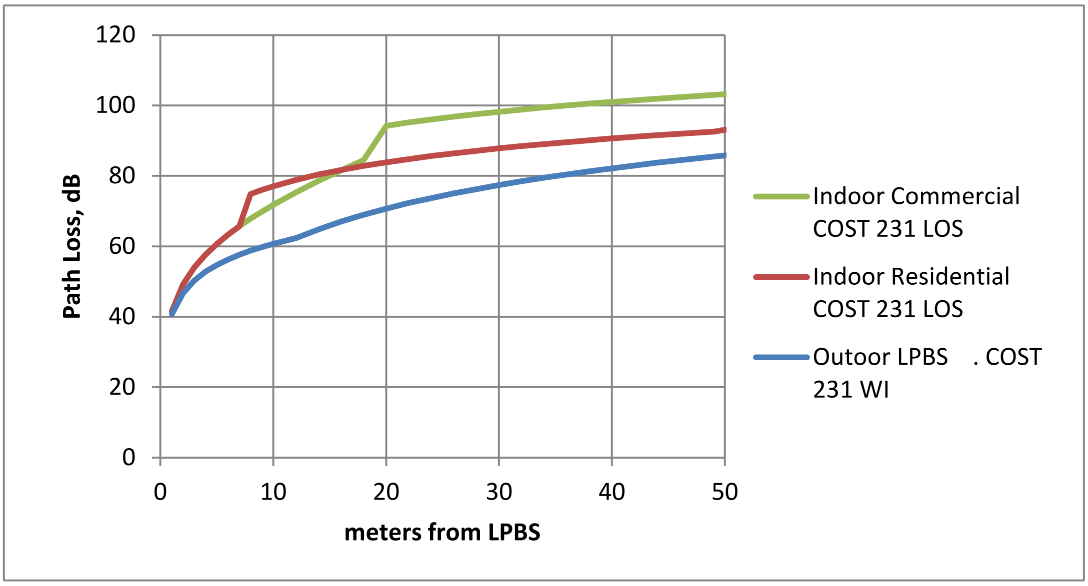


Figure 46 Median Path loss models for unwanted signal from LPBS for indoor and outdoor scenarios.

- **Base station Transmit power**
  - Uniform power spectral density is assumed for downlink transmissions, so half the total Equivalent Isotropically Radiated Power (EIRP) is transmitted in the overlapping 10MHz of the two 20MHz channels in the hybrid scheme.
  - SPBS: Regulatory limit is 61dBm/5MHz, which corresponds to 64dBm /10MHz overlap
  - LPBS transmit powers based on the findings of the low power report [3]
    - Outdoor: EIRP 30dBm / 20MHz, which corresponds to 27dBm/10 MHz overlap
    - Indoor:
      - Residential: 20dBm EIRP, half of which (17dBm) is transmitted in the overlapping 10MHz of hybrid spectrum.
      - Commercial: LPBS EIRP: 27dBm, half of which (24dBm) is transmitted in the overlapping 10MHz of hybrid spectrum.
- **Acceptable interference zone criteria**
  - Interference zone defined as where PR_{SP}/PR_{LP} < 0dB. The interference zone therefore represents the area where a stronger signal is received from the low power base station and a user terminal would normally handover to it. This is a cautious definition, as it is still possible for the UE to maintain connectivity with the standard power base station some way into the zone.
  - The proposed acceptable size of zone (for co-ordination rule) is 50m diameter.

6.4.3 Size of downlink interference zone

6.16 Figure 47 illustrates how the downlink interference zone size is evaluated for an example scenario with the LPBS positioned 205m from the SPBS. The upper graph shows the wanted and interfering signals received by the SPUE as it moves away from the SPBS and past the LPBS. The wanted power PR_{SP} increases with range from the SPBS, whilst the interfering power increases as the LPBS is approached. Received powers vary as a function of the path loss models, which are different for the SPBS-SPUE and LPBS-SPUE paths as detailed later in the assumptions.

6.17 The lower graph in Figure 47 shows the ratio of wanted to interfering signal power PR_{SP}/PR_{LP}, which is indicative of the CIR experienced by the SPUE. The size of interference zone is indicated for a criterion of PR_{SP}/PR_{LP} >0dB, the criterion agreed with Ofcom for the purposes of this study. In this example case, the zone diameter is around 80m. It can be seen that the zone extends slightly further on the far side of the LPBS, and is slightly shorter on the near side. The upper graph shows that this is due to the decreasing power PR_{SP} on the far side.

6.18 Figure 48 presents the interference zone size as a function of LPBS range from the HPBS. The zone size increases as for greater separation between the LPBS and HPBS. The worst case condition is therefore a LPBS positioned at or near the HPBS's cell edge. An example cell edge range of 167m is illustrated on the graph, based on the ITU-R's urban macro scenario which has a Inter Site Distance (ISD) of 500m [21]. At this position, and assuming the criterion of PRSP/PRLP=0dB, the LPBS causes an interference zone of around 67m in diameter. Less strict criterion for interference zones, down to PR_{SP}/PR_{LP} = -10dB, give smaller interference zone sizes.

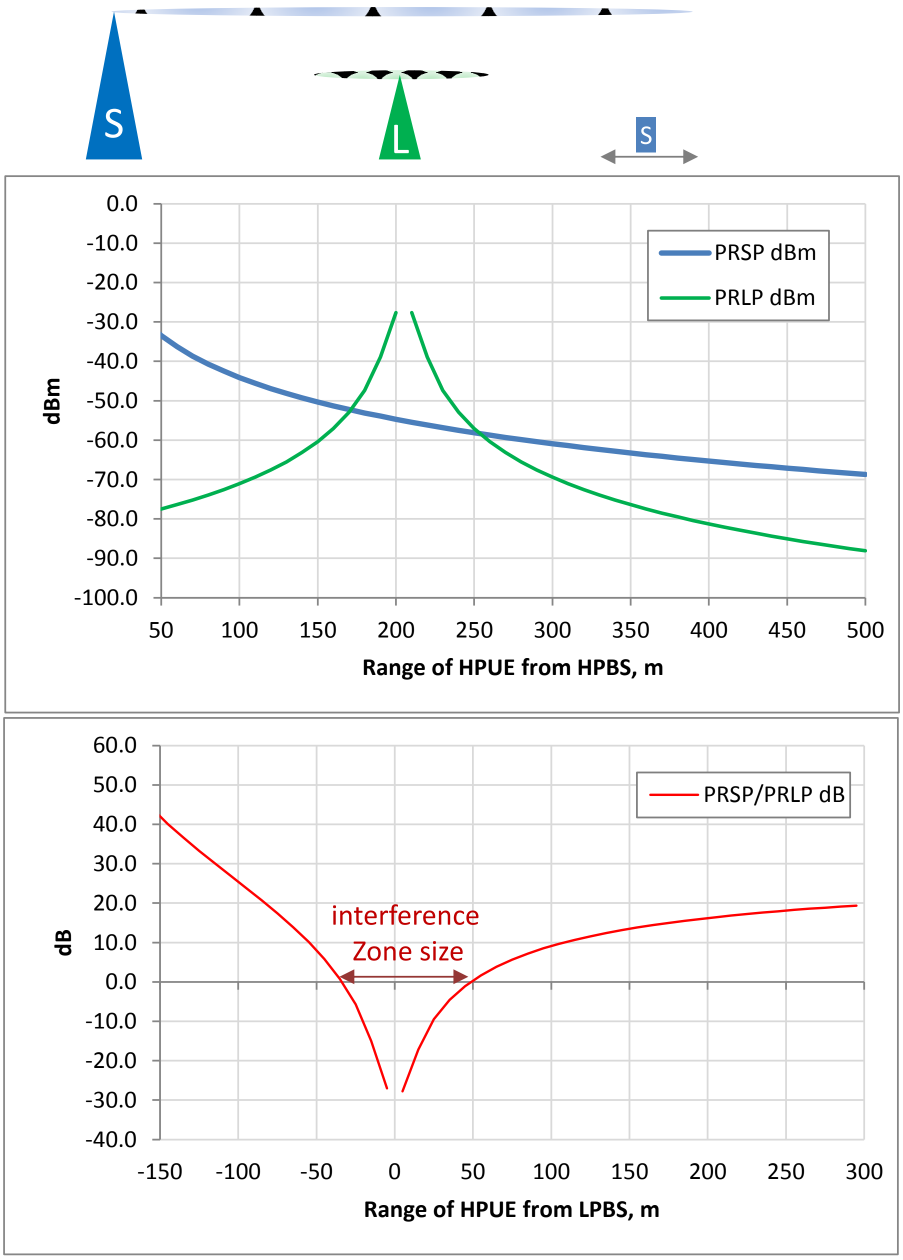


Figure 47 Method for evaluating the downlink interference zone size

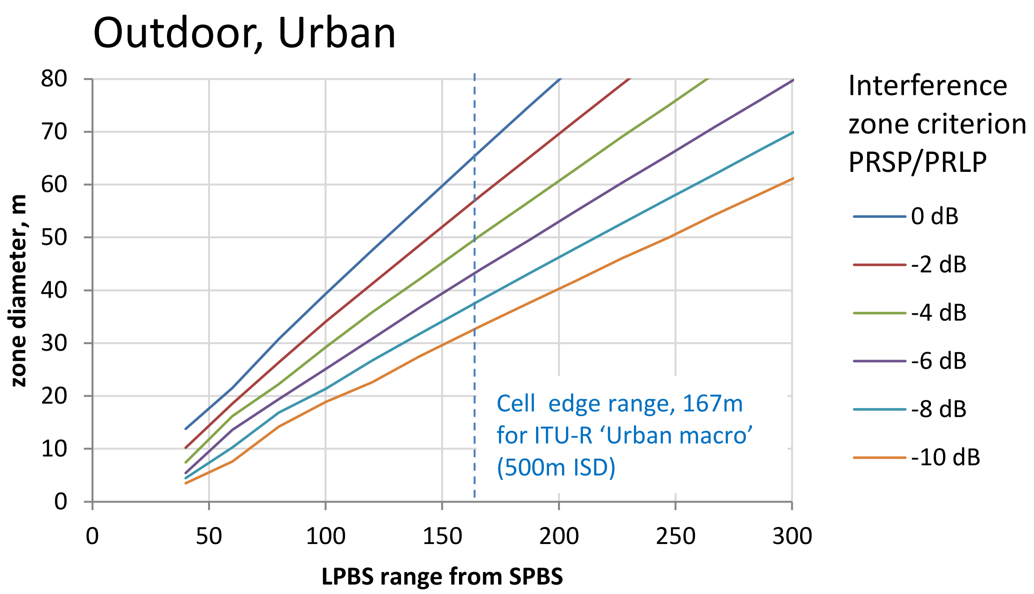


Figure 48 Interference zone size as a function of LPBS range from SPBS

6.4.4 Reducing zone size with measurement based power control

6.19 Reducing the EIRP of the LPBS reduces interference to the standard power network, and thus the interference zone size as illustrated in Figure 49. However, as shown in Figure 48, zone size varies as a function of LPBS position. Given a maximum acceptable zone size of 50m, it is desirable to impose an EIRP restriction only when this zone size would otherwise be exceeded. This can be achieved through 'network listen' measurements by the LPBS, which can detect the challenging scenario where the LPBS is towards the edge of the HPBS's coverage, as shown in Figure 50.

6.20 The LPBS evaluates power received from the SPBS, and sets its EIRP according to following algorithm:

$EIRP_{LPBS}$ = min {$EIRP_{MAX}$, PR_{SP} + Offset - margin} (in dBm)

where:

- $EIRP_{MAX}$ is the regulatory limit for the given LPBS deployment scenario
- PR_{SP} is evaluated using the network listen function of the LPBS. In practice, the measurement for LTE will likely be the Reference Signal Received Power (RSRP), which will represent only a fraction of the total received power across the 20MHz SP channel. This measurement should be scaled to represent the total received power.
- Offset is chosen to give a particular zone size for a given zone criterion.
- The margin represents power setting error of the low power base station. It is recommended to use a margin of 11dB consistent with the UE power tolerance used for uplink protection discussed in paragraph 6.46.
- $EIRP_{LPBS}$ is the total EIRP of the LPBS over the whole 20MHz LP channel.

6.21 This algorithm reduces LPBS power with increasing path loss from macro, limiting zone diameter to a constant size, independent of range. This shows it is possible to protect the SP network by controlling the size of the interference zone by using a LPBS 'network listen' based co-ordination rule. In practice, a trade-off between SP interference zone size and LP cell size will need to be made.

6.22 If LPBSs are unable to make measurements of power received from the SPBS, then they must be located beyond the useful coverage of any SPBS. This may be the case if the low power networks used a different access technology to the standard power network, for example a mix of WiMAX and LTE.

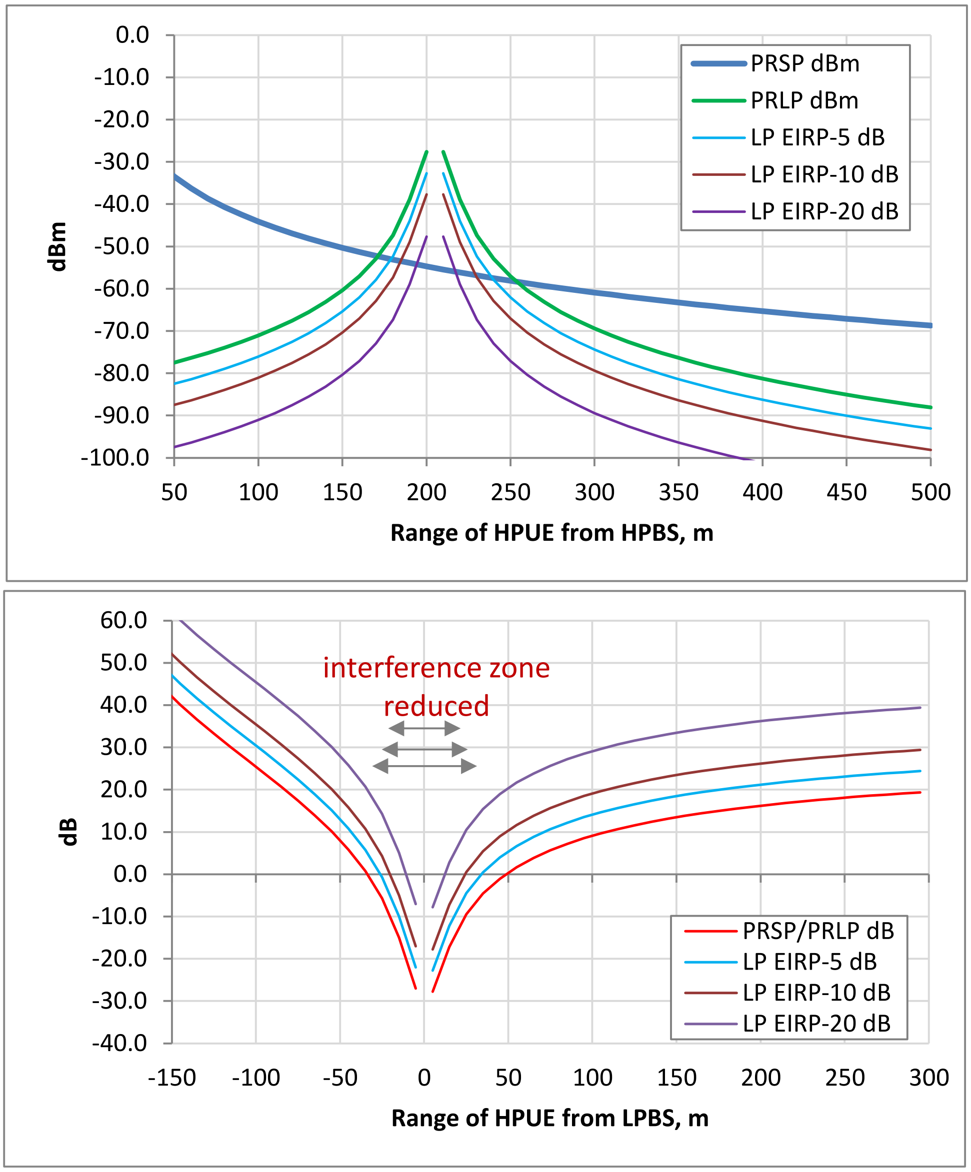


Figure 49 Impact of LPBS EIRP reduction on interference zone size (PRSP/PRLP=0dB)

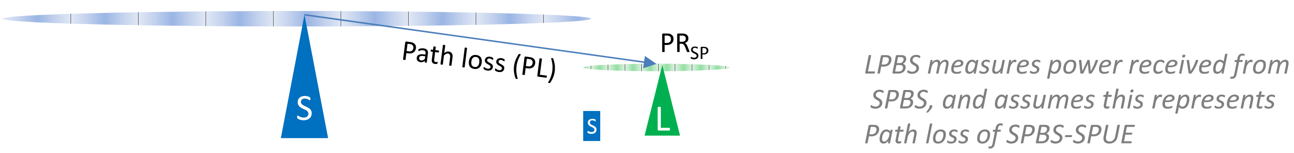


Figure 50 LPBS network listen measurement used to control interference zone size

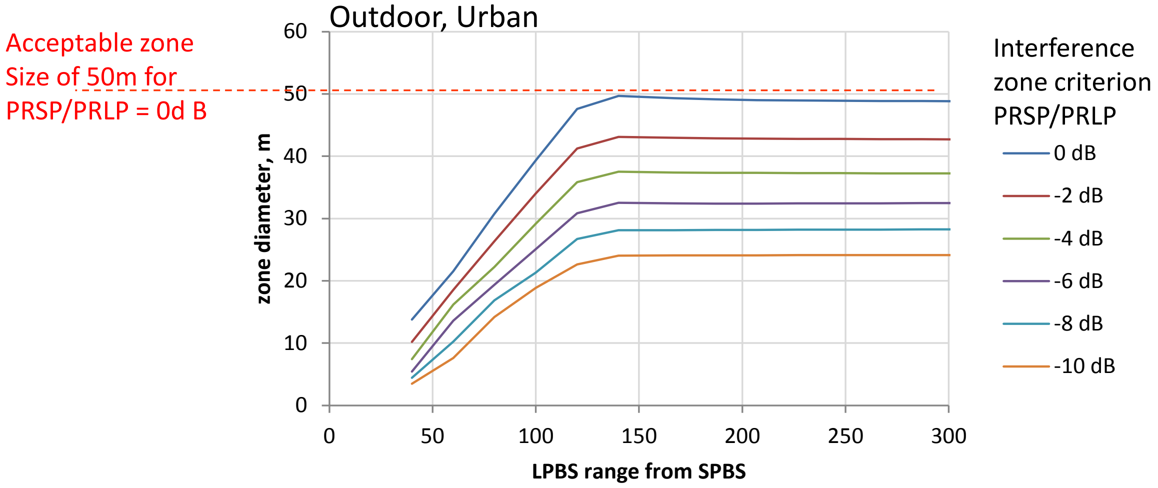


Figure 51 Controlled Zone size based on network listen measurement from LPBS

6.23 Figure 51 shows the effect of the interference mitigation algorithm. Zone size increases up to a limit (in this example at a LPBS-SPBS separation of around 130m), and is then constant for greater separations. For less strict zone criterions, the zone size limits are also smaller.

6.24 Figure 51 shows an example where the zone diameter is limited to the proposed maximum acceptable 50m based on the 0dB criterion. This requires an offset value of 75.6dB to achieve this in an outdoor scenario.

6.4.5 Indoor scenarios

6.25 The interference zone size can be affected if the LPBS causing it is located inside a building. Here we consider two indoor scenarios representing residential and commercial buildings. Figure 52 illustrates the evaluation of zone size for the indoor case, highlighting the form of the path loss models around the building itself. Details of the model assumptions and transmit powers are given in the assumptions section.

6.26 It can be seen in Figure 52 that the walls of the building containing the LPBS cause additional path loss when signals pass through them. When the SPUE is outside the building, this improves isolation from the LPBS by reducing unwanted signals. However, when the SPUE is inside the building, there is no additional loss for the unwanted signal, but instead the wanted signal is attenuated by the building’s exterior walls. It will be shown later that this causes the zone size to ‘lock on’ to the building size over a certain range of LPBS-SPBS separations.

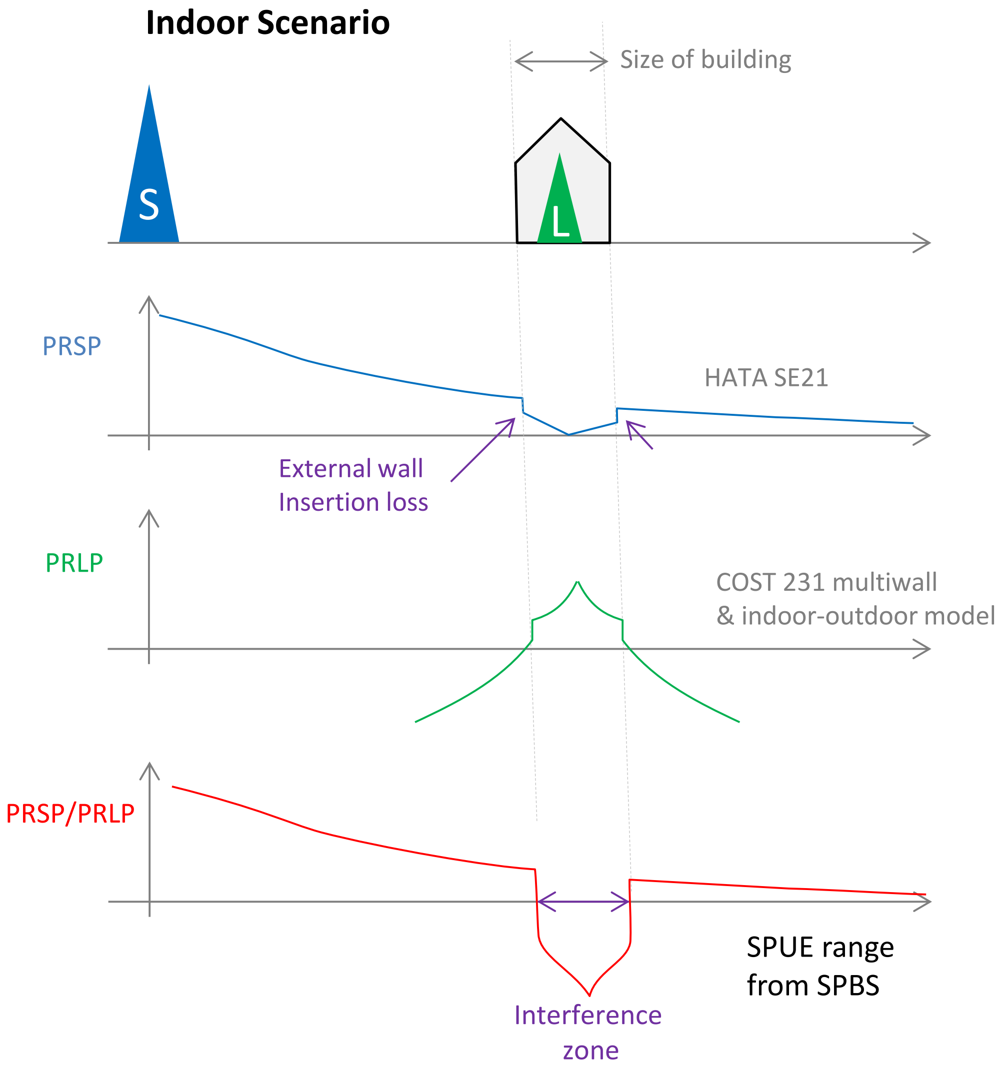


Figure 52 Evaluation of Interference zone size in Indoor scenario

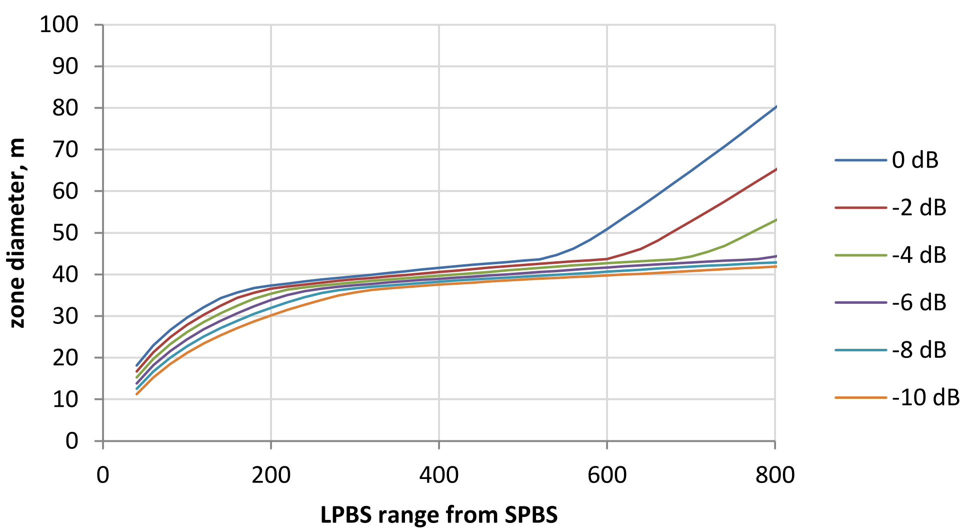


Figure 53 Zone size for indoor commercial scenario (40m building)

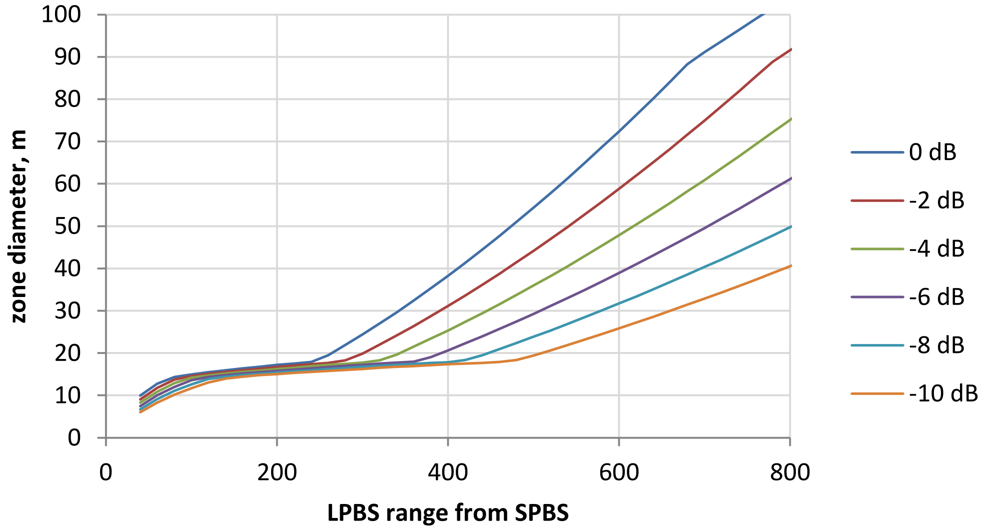


Figure 54 Zone size for indoor residential scenario (16m building)

6.27 Figure 53 and Figure 54 show the zone sizes for indoor commercial and residential scenarios, respectively. The main trend in both cases that the zone size 'locks on' to the building size over a range of LPBS-SPBS separations.

6.28 Figure 55 shows a comparison of zone sizes versus LPBS-SPBS separation for the outdoor and indoor scenarios. In general, zone sizes for indoor scenarios are smaller, showing the additional protection obtained from the walls of the building. The 'lock on' to building size can be seen for the 16m residential and 40m commercial buildings. For short LPBS-SPBS separations, the residential scenario offers more protection for the SPUEs. For separations larger than around 400m, the larger commercial buildings results in higher path loss, which more than compensates for the slightly higher transmit power.

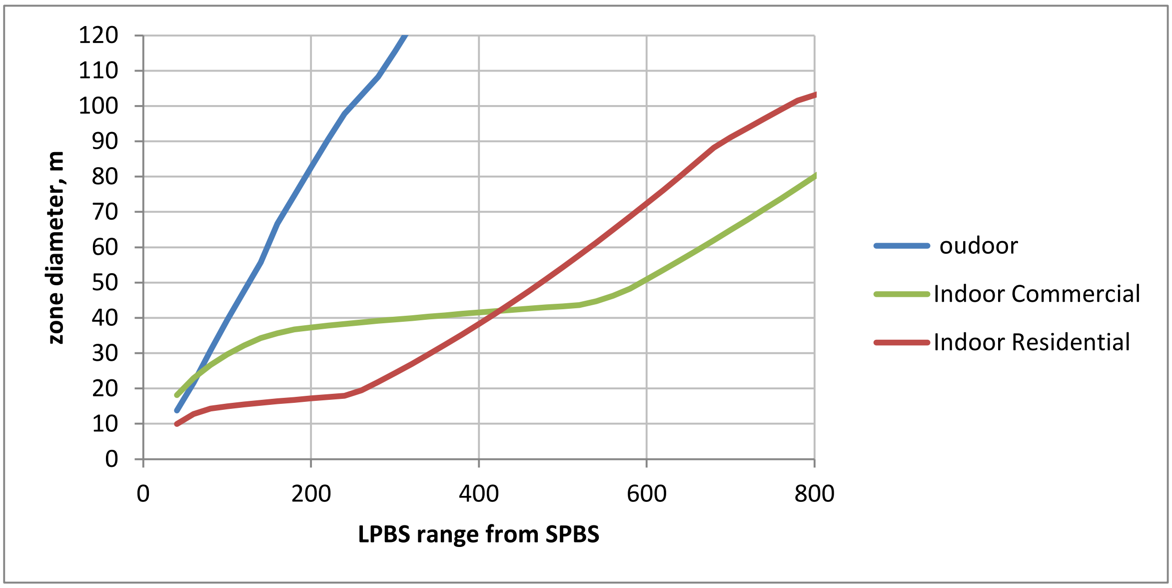


Figure 55 Zone size for outdoor and indoor scenarios, using PRSP/PRLP=0dB criterion

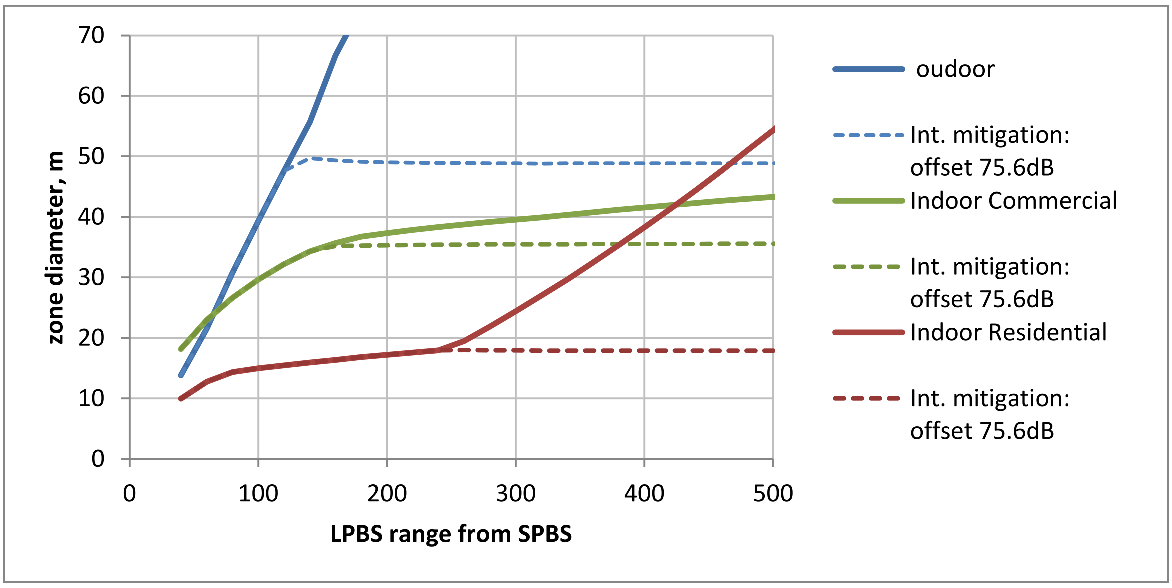
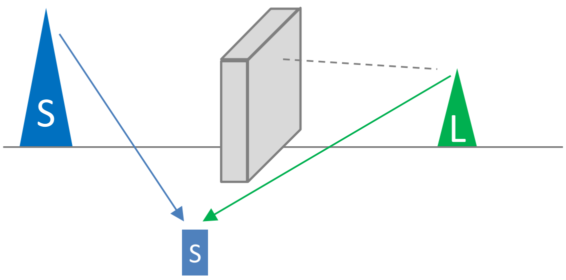


Figure 56 Zone size for outdoor and indoor scenarios with interference mitigation (0dB criterion)

6.29 Figure 56 shows the impact of interference mitigation on the outdoor and indoor scenarios. As shown previously, the offset is chosen to limit the zone size for an outdoor LPBS to a 50m diameter. Since the indoor LPBS scenarios offer increased protection for the SPUEs, the same offset results in smaller interference zone sizes in these cases. This validates the use of the outdoor case in choosing an offset value for the maximum allowable zone size of 50m

6.4.6 Further refinement of the downlink interference mitigation schemes



SPUE can 'hear' both SPBS and LPBS, but LPBS and SPBS cannot hear each other

In this case, SPBS→LPBS path loss is not a good proxy for SPBS→SPUE path loss needed to protect the SP downlink

Figure 57 Illustration of the hidden node problem in the case of the LPBS network listen measurement

6.30 The downlink co-ordination rule described in this study makes use of a 'network listen' measurement by the LPBS. This is assumed to be representative of the path loss of nearby SPUEs to their serving SPBS. In many cases this is a valid approximation; however scenarios such as the hidden node shown in Figure 57 could result in this approximation being poor. An improvement on the LPBS network listen measurement would be to base LPBS EIRP control on measurements of the SPBS made by LPUEs and reported back to the LPBS, as shown in Figure 58. These would be a better approximation to the SPBS-SPUE path loss, and could avoid the hidden node problem.

6.31 Downlink protection for the SP network could further be improved by using measurements from the SPUEs themselves. If both PRHP and PRLP could be measured in quick succession by the SPUE and reported back to the LPBS in question to control its EIRP, it would be an accurate way to protect SPUEs from downlink interference. Such a scheme would require some information sharing between the SP and the LP networks as illustrated in Figure 59. Measurement reports from SPUEs would need to be stored in a database which could be accessed and acted upon by base stations in the low power network.

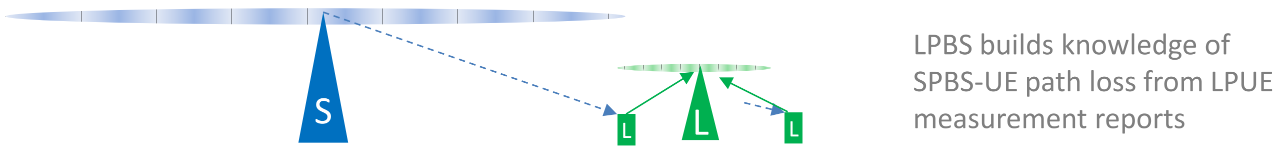


Figure 58 Enhanced downlink interference mitigation using measurements from LPUEs

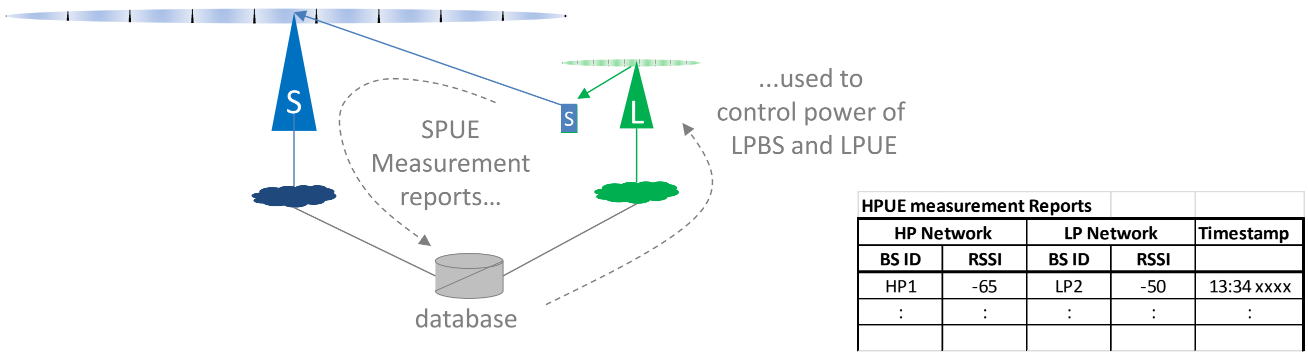


Figure 59 Information sharing of SPUE measurement reports to enhance SP downlink protection

6.5 Interference to the standard power uplink

6.5.1 Challenging scenario for the standard power uplink

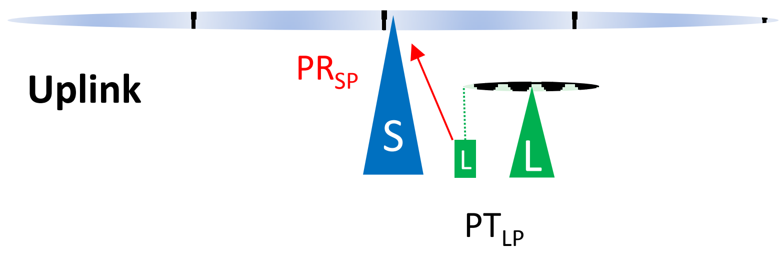


Figure 60 challenging scenario for interference to standard power uplink

6.32 Uplink interference is caused when unwanted LPUE transmissions are received by the SPBS. The most challenging scenario for the SP uplink is when the LPUE is at the edge of its cell (and is therefore transmitting high power) and the LPUE is close to the SPBS (and therefore has little path loss to protect the SPBS).

6.33 Unlike the downlink which creates interference zones around the LPBS itself, uplink interference acts to de-sensitise the SPBS receiver, which affects all SPUEs served by that SPBS across the whole cell area.

6.5.2 Method and assumptions for the uplink analysis

6.34 The overall method for analysing uplink interference and defining co-ordination rule is as follows:

1) Define the acceptable level of interference that can be received by the SPBS
2) Evaluate for the challenging scenario the maximum power that the LPUE can transmit
3) Define algorithm for co-ordination rule to control LPUE power for any scenario which provides the necessary protection to the SP uplink

6.35 The assumption for the acceptable interference criterion is that the maximum interference power from a LPUE in a hybrid channel configuration should be no more than 'normal' interference from another standard power system in an adjacent channel, as illustrated in Figure 61. This has been evaluated from 3GPP co-existence studies to be -67.5dBm / 20MHz. See elsewhere in this report.

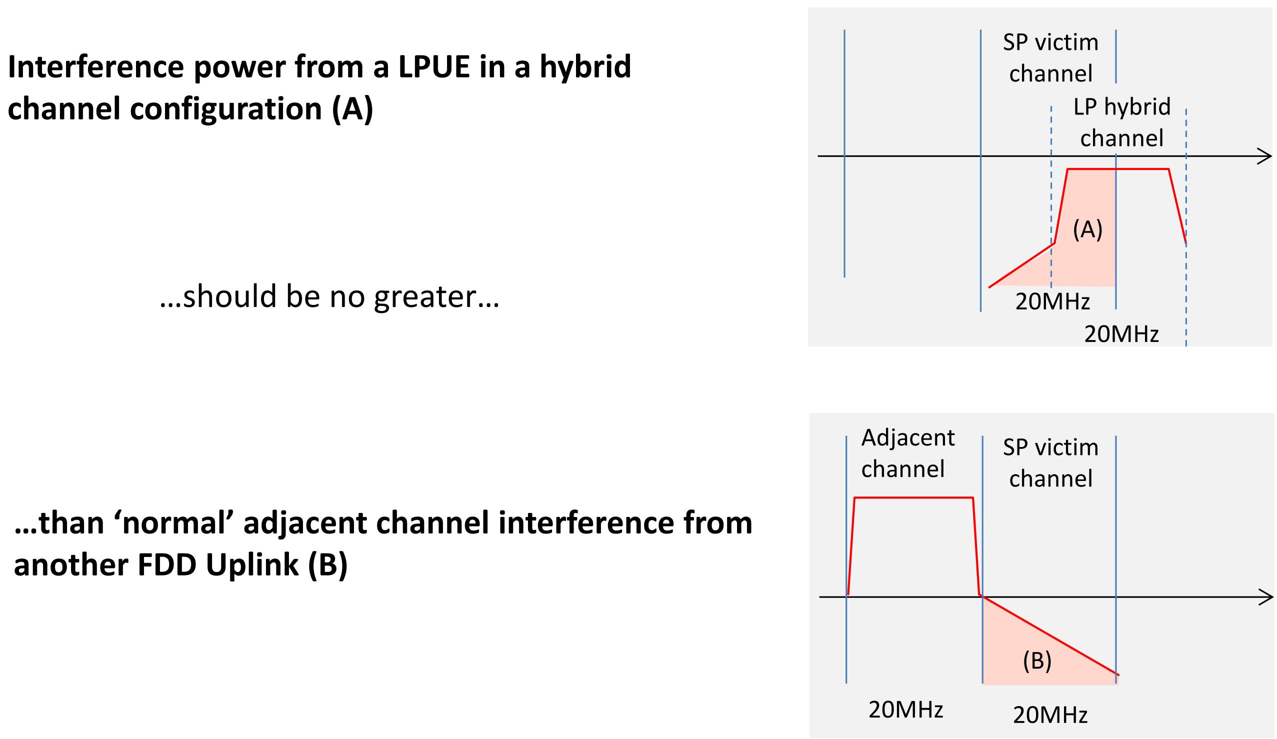


Figure 61 Criterion for an acceptable level of interference to the standard power uplink

6.5.3 Maximum LPUE power for the challenging scenario

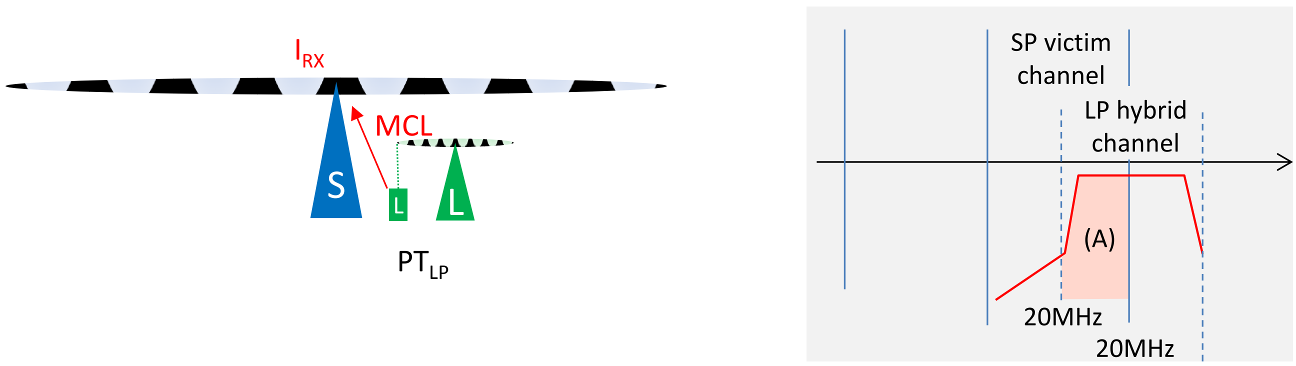


Figure 62 Calculation of Maximum LPUE power in the most challenging scenario

6.36 In the challenging scenario illustrated in Figure 62, the LPUE is located close to the SPBS and there is little path loss. This is assumed to be the Minimum Coupling Loss (MCL) of 70dB defined by 3GPP for co-existence studies [9].

6.37 It is assumed that the interference to the SP victim is dominated by the in-channel part of the LPUE transmission, labelled (A) in Figure 62.

6.38 Interference power received by the SPBS, I_{RX} is given by:

I_{RX} (dB) = PT_{LP} - MCL

6.39 To comply with the interference criterion, we need

$I_{RX} < -67.5$dBm / 20MHz

Therefore:

$PT_{LP} < -67.5 + 70 = +2.5$dBm

6.40 Therefore in the most challenging scenario, LPUEs should restrict their EIRP to +2.5dBm within the overlapping 10MHz of the hybrid channel to avoid causing unacceptable interference to SPBSs.

6.41 The LTE uplink uses Single Carrier Frequency Division Multiple Access (SC-FDMA) as modulation and multiple access scheme. This constrains UEs to transmit over a continuous range of frequencies. For this challenging scenario it can be assumed that a UE at the edge of its cell will need to concentrate its transmitted power over a narrow range of frequency resources in order to achieve sufficient SINR. It is assumed that the UE will transmit its entire EIRP allowance in the overlapping 10MHz of the hybrid scheme.

6.42 The 3GPP analysis on which the interference criterion is based provides data on the uplink throughput loss for the 5% percentile 'cell edge' SPUEs with varying levels of uplink interference. Combining this with the calculation above for maximum allowable LPUE transmit power, Figure 63 shows the potential throughput loss for different LPUE transmit powers. In their co-existence study, 3GPP used a 10% throughput loss as the basis for analysis and we have adopted this same approach [9]. Full details of this interference criterion are provided in the Appendix.

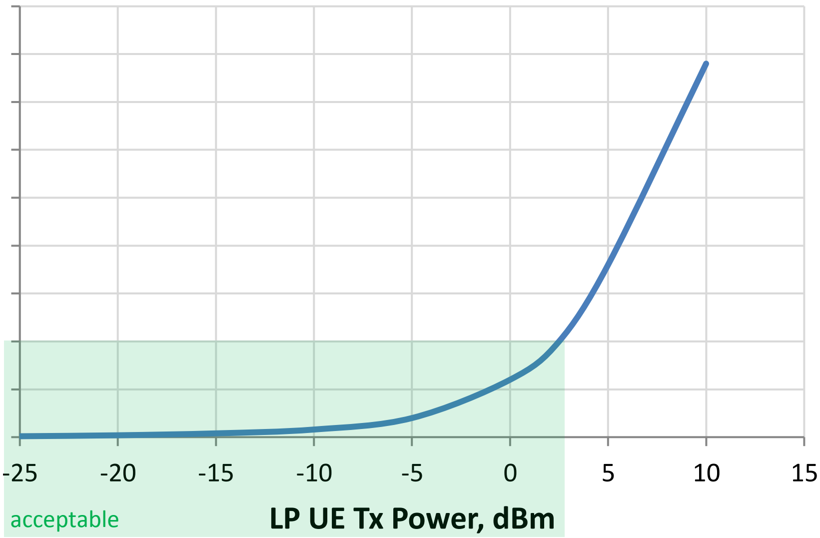


Figure 63 Potential throughput degradation to 5%ile cell edge UEs in the standard power network as a function of increasing LPUE transmit power, when LPUE is in the challenging scenario.

6.5.4 Interference mitigation to protect the SP uplink

6.43 The interference to the SP uplink is product of the LPUE transmit power and the path loss from the LPUE to the SPBS. Given that the LPUE is able to measure the former and set the latter; interference can be limited to acceptable levels in challenging scenarios. Figure 64 illustrates such a measurement:

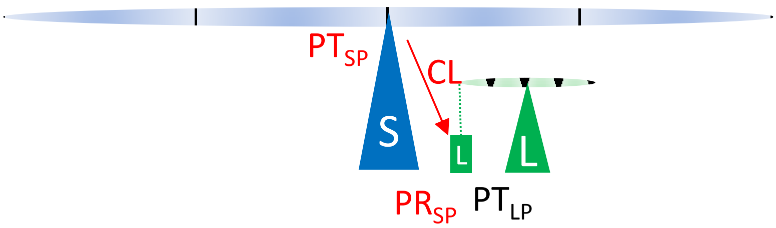


Figure 64 Using LPUE measurements to protect the SP uplink

6.44 The LPUE measures Coupling Loss (CL) to the SPBS. This is achieved by measuring the received power from the SPBS PRSP and subtracting from it the transmitted power PT_{SP}, which for LTE is included in the system information broadcast, which must be read before a UE can make a measurement.

$CL = PT_{SP} - PR_{SP}$

6.45 This coupling loss is then used to control the EIRP of the LPUE thus:

Maximum LPUE Power = min(Coupling Loss-67.5dBm - margin, UE Power limit)

6.46 The margin is an allowance for UE measurement error and power setting error. The LTE UE Radio Frequency (RF) spec 36.101 states that the absolute power tolerance (which includes both variables) is ±11dB [9], so the margin is assumed to be 11dB. It should be noted that this tolerance represents an initial 'start-up' power setting for the UE based on a measurement. Power setting accuracy would subsequently be improved through feedback from the controlling base station. Thus an 11dB margin might be overly cautious.

6.47 The UE power limit is defined by 3GPP as 23dBm ±2dB [9].

6.48 Regarding a LPBS controlling multiple UEs, it is preferable for each UE to have its power individually capped based on its own measurements of the coupling loss with the SPBS. The LTE standard provides a toolkit of techniques with which to control UE transmit powers [22]. Although feasible within the control of the toolkit, individual per UE power capping may require a special implementation, which may limit the flexibility of the power control. Cell wide UE power capping would be simpler to implement and could be based on the worst case measurement of coupling loss from all the LPUEs served by the LPBS.

6.49 Figure 65 shows a plot of the co-ordination rule, which limits LPUE transmit power as a function of measured coupling loss to the SPBS. This includes the 11dB margin, which reduces the +2.5dBm limit for 70dB MCL, down to -8.5dBm. The margin does not limit the maximum EIRP of the UE.

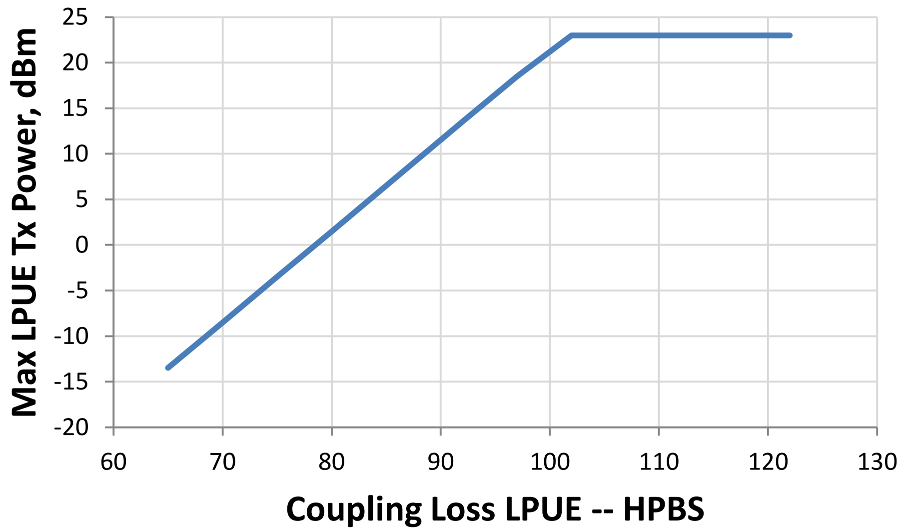


Figure 65 Allowable LPUE transmit power as a function of measured coupling loss

6.6 Recommendations

6.50 When using the hybrid approach to shared spectrum, the low power base station and UEs should control their transmit powers based on measurements in order to limit interference to the standard power network to within agreed acceptable limits.

6.51 **For the downlink**: The LPBS evaluates power received from the SPBS, and sets its EIRP according to the following algorithm:

$EIRP_{LPBS} = \min \{EIRP_{MAX}, PR_{SP} + Offset - margin\}$ (in dBm)

where:

- $EIRP_{MAX}$ is the regulatory limit for the given LPBS deployment scenario

- PR_{SP} is evaluated using the network listen function of the LPBS. In practice, the measurement for LTE will likely be the Reference Signal Received Power, which will represent only a fraction of the total received power across the 20MHz SP channel. This measurement should be scaled to represent the total received power.
- Offset is chosen to give a particular zone size for a given zone criterion.
- The margin represents power setting error and is assumed to be the same for the LPBS as for the UE (11dB)
- $EIRP_{LPBS}$ is the total EIRP of the LPBS over the whole 20MHz LP channel.

6.52 The above rule will limit outdoor interference zones to 50m, where an interference zone is defined by the locus of points where PRSP/PRLP >0dB

6.53 **For the uplink:**The LPBS monitors SPBS-LPUE coupling loss based on measurements made by the LPUE, and limits the LPUEs transmit power according to the following algorithm:

Maximum LPUE Power = min(Coupling Loss-67.5dBm - margin, UE Power limit) (in dBm)

where:

- Coupling loss is determined by the LPUE from measured power from the SPBS and the transmitted power which can be determined from the system information broadcast, which must be read before any measurement can take place.
- Margin represents the power setting ability of the UE, and includes the measurement uncertainty. A figure of 11dB is taken from 3GPP specifications.
- UE power limit is +23dBm ±2dB, as specified by 3GPP
- Where per UE power capping is not possible or appropriate, a per cell power cap may be applied based on the worst case (lowest) coupling loss measurement.

6.54 Where the LPBS and LPUE are unable to make measurements of the SP network – e.g. in the case where a non-compatible technology is deployed, the LPBS must not be deployed within the coverage area of any SPBS. Coverage area size will vary depending on the class of SPBS. Wide area SPBSs which transmit more power will incur wider exclusion zones for LPBSs. It may be necessary for the standard power licensee to share information with LP licensees as to the location and class of deployed SPBSs.

6.7 Answers to study questions

Study Question	Answer
1.19 Analyse the potential impact on a standard-power operator who shares access to 10 MHz of spectrum with low-power operators.	
Assume that the standard-power operator has a block of 20 MHz, where 10 MHz is not shared and in the other 10 MHz low-power operators are permitted	The hybrid channelization plan has been used in the analysis
Assume the low-power operators have access to 20 MHz in total: 10 MHz spectrum for low-power only and 10 MHz spectrum as an underlay to a 20 MHz standard-power licence. The standard-power operator has priority in the shared 10 MHz	The analysis has considered the protection of the standard-power network
1.20 Include the following scenarios:	

a) Impact of “hole-punching” in the standard-power network coverage due to downlink interference. Since this is more likely to occur in low signal conditions, how can low-power access points be sufficiently certain that they will be able to avoid causing this problem?	The downlink analysis evaluates the size of 'interference zones' as a function of low power base station separation from the standard power base station. The zone size increases with separation. A co-ordination rule is proposed where the low power base station makes measurements of power received from the standard power basestation. These measurements are then used to control the EIRP of the low power base station such that the interference zone limited to an acceptable size. An algorithm has been developed and parameters defined to meet Ofcom's proposed acceptable size of 50m zone diameter for an interference zone where the power received from the low power base station is no higher than that received from the standard power base station. In order to completely avoid any interference zones, the low power base station would need to reduce power or switch off whenever a standard power user terminal entered its coverage area. This would require sharing of standard power user terminal measurement reports with the low power network.
b) Impact of base station receiver blocking on the standard power network, caused by terminals attached to a low-power access point.	The uplink analysis uses the same criterion defined elsewhere in this report that interference from a low power user terminal should be no higher than that normally received by another system in an adjacent channel. From this, the degradation to 5%ile cell edge users of the standard power network can be determined for various low power user terminal transmit powers. A co-ordination rule is proposed where the transmit power of the low power user terminal is controlled according to the coupling loss between that terminal and the standard power base station. Parameters are given which limit the interference caused to an acceptable level
b) Identify other relevant scenarios and agree them with Ofcom.	The downlink analysis includes a range of scenarios including outdoor, indoor residential and indoor commercial.
1.21 Determine the feasibility of underlay networks protecting standard-power use and providing sufficient confidence that existence of standard-power coverage will be detected and that procedures will be available to cease transmission in the underlay spectrum.	Interference zones in the standard power downlink can be limited to acceptable sizes provided the low power network is able to make measurements of the power received. This same co-ordination rule could be used to cease transmissions altogether if deemed appropriate. ‘Network listen’ measurements by the low power base station will be sufficient for most cases, but scenarios such as the hidden node could result in under-compensation. Network listen could be augmented by measurement reports from low power user terminals, in order to avoid such scenarios. Sharing of standard power measurement reports between the networks would improve the accuracy of the downlink inference mitigation scheme further. Protecting the standard power uplink can be reliably

	achieved with measurements made by the low power user terminals themselves. Measurements of coupling loss with the standard power base station can be used to limit the power of each UE individually, or if this is deemed to reduce the flexibility of the low power uplink power control, then a cell-wide power cap could be applied based on the worst case (lowest) coupling loss. Should the low power equipment not have the ability to make measurements of the standard power network, then minimum separation distances would need to be applied to avoid interference.
1.22 Assess whether information sharing between the low-power and standard-power operators will be an essential component of managing the hybrid approach.	Information sharing of measurement reports from the standard power user terminals would help to refine mitigation of interference to the standard power downlink. Information sharing is not needed to protect the standard power uplink. Should the low power equipment be unable to measure the standard power network and minimum separation distances apply, information sharing of the standard power base station locations and power classes would be needed in order to define exclusion zones for the lower power shared access base stations.

7 D: Number of low power licences

7.1 Ofcom would like to determine the maximum number of low-power licensees who can share spectrum when covering the same geographical area

7.1 Long Term Evolution (LTE) was originally designed for operation in licensed spectrum where each operator has a dedicated channel for their equipment. The channel bandwidth is re-used in a number of cells, each covering a different geographical area. It is challenging to maintain performance in the 'cell edge' regions of overlapping coverage.

7.2 Studies for the standardisation of Home NodeBs and Home eNodeBs (Universal Mobile Telecommunications System (UMTS) and LTE femtocells respectively) identified ways in which an operator could manage interference in consumer deployed low power cells within the standard power coverage area, using the same channel as their standard power network. Techniques identified were: Time shifting, carrier offsetting and frequency partitioning [23]. These techniques were further described in [3].

7.3 This analysis considers how multiple overlapping cells from different operators might operate in both a dedicated shared channel and in a 'hybrid' approach with two 20MHz LTE channels occupying 30MHz of spectrum with a 10MHz overlap.

7.4 It should be noted that licensee limitations and co-ordination requirements only apply to co-existing cells from multiple operators that are providing coverage to the same areas. 'Isolated' cells will not need to co-ordinate. The distinction could be made dynamically by 'listening' for other cells.

7.5 There is no fundamental limit to the number of licensees which could share a channel, provided they do not all wish to provide services over the same geographical area. Licensees confining their transmissions to mutually exclusive areas – such as in-store coverage for different chains of shops for example – would need minimal co-ordination.

7.6 The study focuses on the number of licensees that could provide services to the same geographic areas e.g. public places.

7.2 Study questions

7.7 Assess the maximum number of licences that could be issued for low-power shared access in 2.6 GHz spectrum, based on the following:

- Assume that low-power licensees are required to agree a code of practice to manage situations where several or all of them are seeking to use the spectrum in a geographical area;
- Include the two scenarios of (a) 10 MHz low-power only and (b) hybrid approach of 10 MHz low-power and a further 10 MHz underlay;
- Identify any limiting factors that place an absolute cap or significant constraint on the number of licences.

7.3 Approach and assumptions

7.8 The analysis here considers how many instances of the LTE frame structure could be successfully transmitted and received over the same geographical area in shared spectrum. Figure 66 illustrates the elements of the frame structure that are relevant to the analysis.

7.9 This initial study focuses on the downlink aspects, as these are critical for user terminals to be able to detect and synchronise to serving networks. Once connectivity is established, the uplink is needed not only for data upload, but also for feedback of downlink control signalling.

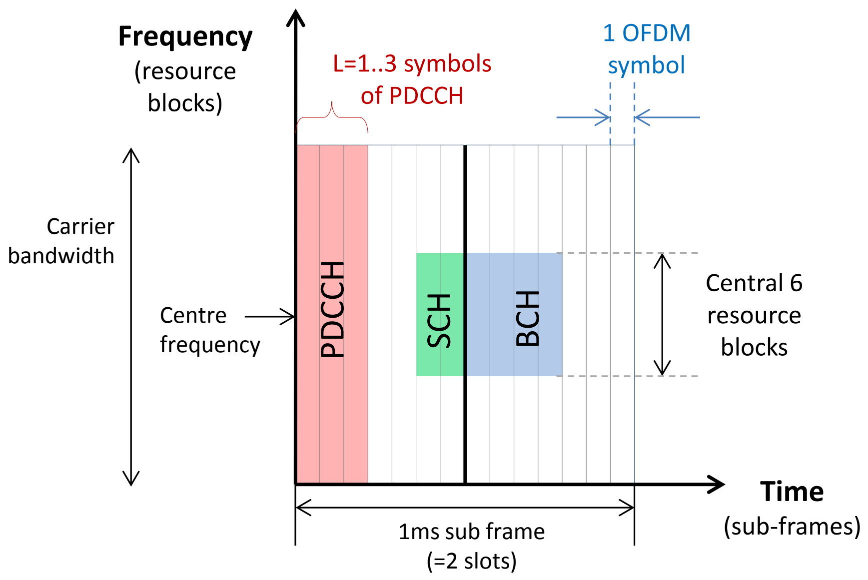


Figure 66 Key elements of the LTE downlink frame structure relevant to this analysis

7.10 LTE transmissions broadly comprise user data and control information. These exist in specific (time, frequency) locations within the frame structure. Figure 66 illustrates the locations of the three main downlink control channels, noting that there are other control channels which share the same locations as the Physical Downlink Control Channel (PDCCH). The user data can occupy all areas not used by the control channels.

7.11 In LTE the downlink resource is divided into a grid of (time, frequency) resources. In the time domain, 7 Orthogonal Frequency-Division Multiplexing (ODFM) symbols comprise a 0.5ms slot, and two slots make a 1ms sub-frame. Although not shown, 10 sub-frames make up a radio frame. The frequency domain is divided up into many OFDM 'tones' or subcarriers which are grouped together into larger Resource Blocks (RB). A 20MHz bandwidth contains 100 such RBs. Strictly speaking, an RB is a unit of frequency (180kHz) lasting one sub-frame (1ms), and is generally the smallest unit of resource that can be scheduled for user data transmissions.

7.12 In the interests of clarity, Reference Signals (RS) are not shown, and are distributed across the entire (time, frequency) resource. It is assumed that reference signals will function correctly in the presence of interference once the cell ID has been obtained from the sync channel and they can be demodulated using that cell IDs

7.13 It is assumed multiple cells can operate in the same channel and location provided the control channels are not transmitted on the same (time, frequency) locations. Parameters which can be varied to enable co-existence are the relative frame timing, carrier position and carrier bandwidth.

7.14 The following control channels are considered. Their locations are taken from [22] and [24].

7.14.1 PDCCH: Often described as L=1,2 or 3, which denotes the number of OFDM symbols occupied by PDCCH at the beginning of every sub frame and across the full channel bandwidth.

7.14.2 Synchronisation Channel (SCH): Occupies the last two OFDM symbols in slots 1 and 10 of the 20 slot radio frame. Only in central 6 RBs of the channel bandwidth.

7.14.3 Broadcast Channel (BCH): Occupies the first four symbols of slot 2 in each 10ms radio frame. Central 6 RBs only.

7.15 It is assumed that data channel power in one cell can be reduced to protect control channels in co-existing cells.

7.4 Hybrid Channel Approach

7.16 The hybrid channelization approach is illustrated in Figure 67, showing the locations of the 'vulnerable' control channels located in the central 6 RBs for the downlink, and the edge RBs on the uplink. This diagram shows the central location of the downlink SCH and BCH, but not the bandwidth-wide PDCCH.

7.17 A 20MHz LTE system occupies the central 18MHz with resource block transmissions, leaving some 'guard RBs' at the edges. In the hybrid approach, Figure 67 shows that the vulnerable central 6 RBs of the both the standard and low power networks sit within the 'guard RBs' of each other, and so will benefit from some protection. There will still be some interference due to roll off of spectral emissions in this guard region, which could be improved by avoiding transmissions in the outer RBs of the downlink.

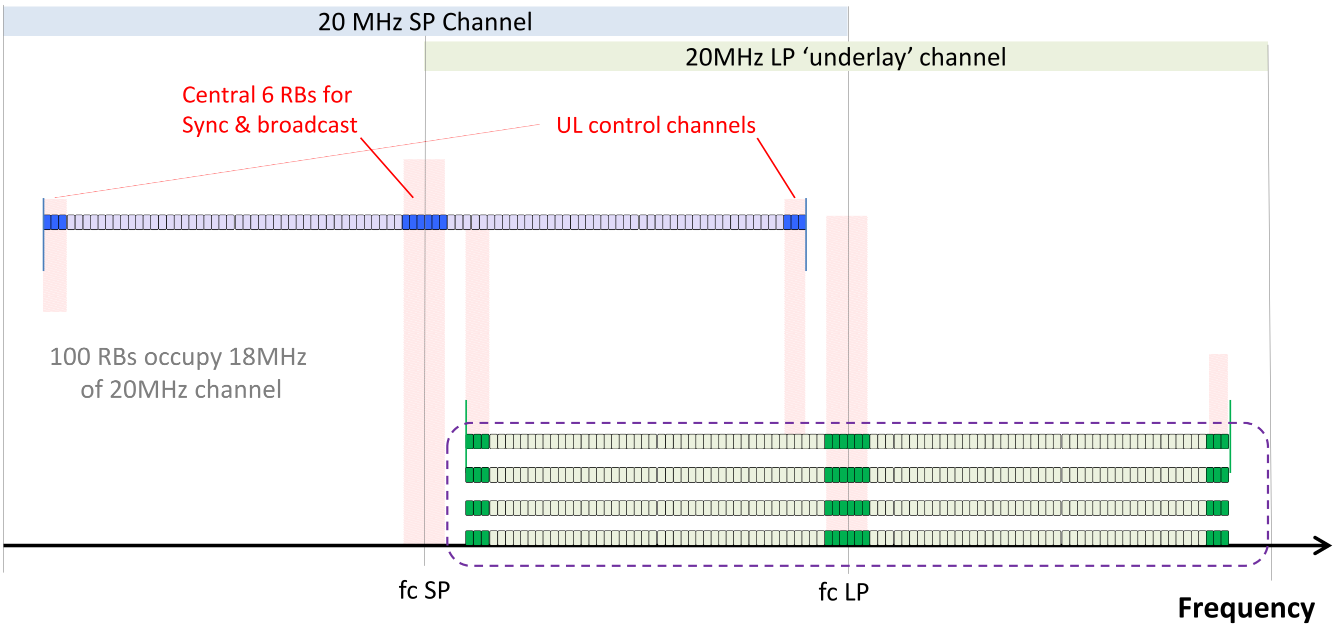


Figure 67: Frequency domain layout for the hybrid approach

7.18 The uplink control channels are located at the edges of the bandwidth, and like the downlink there is no alignment to cause interference between the standard and low power networks. The multiple low power networks may need to co-ordinate to avoid interference. It should be noted that the outer RB control channels are only needed in the absence of uplink data transmissions, onto which control information can be 'piggybacked'.

7.4.1 Time shifting

7.19 Whilst the standard power and any given low power network benefit from protection in the frequency domain, the multiple low power networks will need to share the same frequency resources for SCH and BCH transmissions. Furthermore the bandwidth wide PDCCH cannot benefit from any protection in the frequency domain, and so the time domain protection must be considered for these cases.

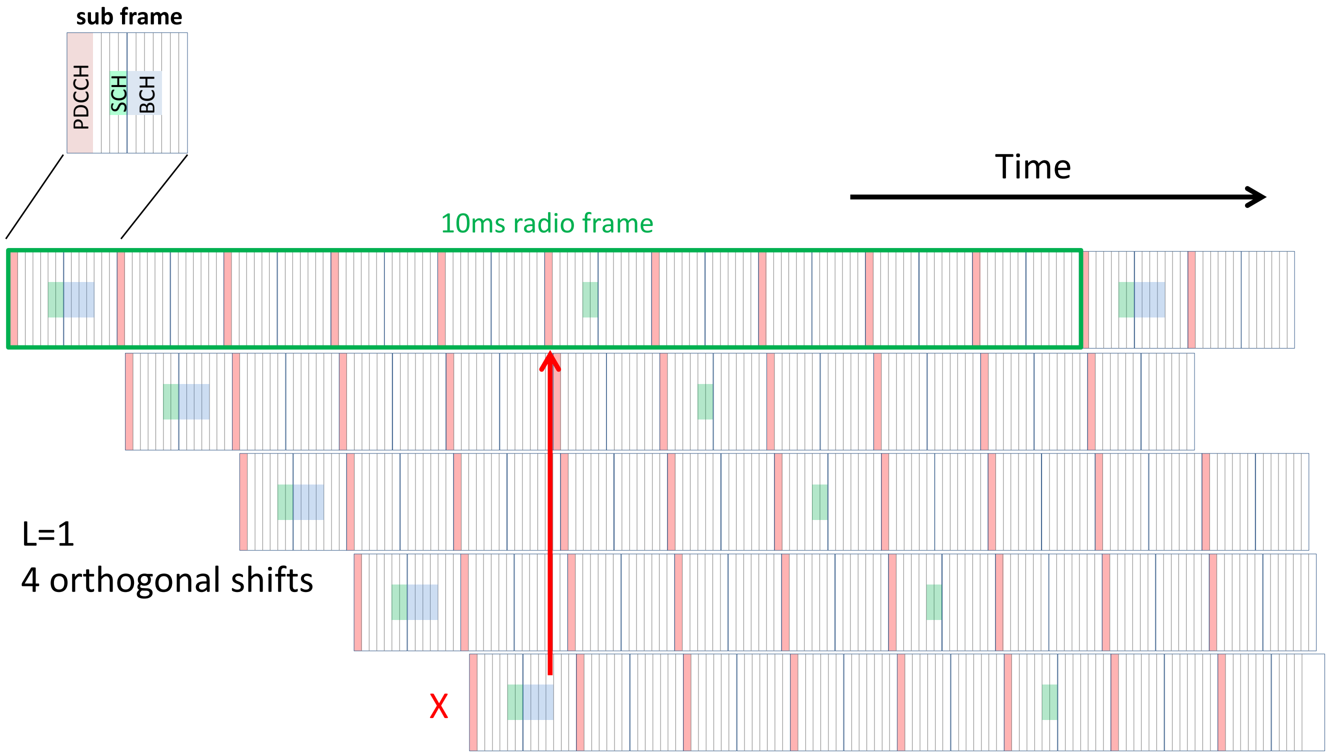


Figure 68: Time domain consideration of interference between time-shifted cell transmissions (dedicated)

7.20 Figure 68 provides a time domain analysis of interference between multiple co-located cells on the same carrier frequency, which can use time shifting to avoid simultaneous transmission of control channels. This represents only the dedicated low power shared access channel, and does not consider the standard power network.

7.21 It is assumed that each low power cell uses only one symbol of PDCCH (L=1), as with their small coverage area they are unlikely to be serving many user terminals simultaneously as compared with a macrocell.

7.22 Figure 68 shows that there are four possible orthogonal time shift positions where the control channels do not coincide. An attempt at a fifth shift position in the bottom row would cause interference between the BCH and the PDCCH of the top row.

7.23 Applying carrier offsetting to avoid frequency domain overlap of the SCH and BCH of the different licensees would allow more sharing, but the system bandwidth would need to be reduced.

7.24 The above time domain analysis shows that four licensees could share the channel if they use one symbol of PDCCH (L=1). If the cells needed to use more resource for PDCCH, such as L=2 or L=3, only two orthogonal time shifts would be possible, as shown in Figure 69.

Figure 69 Time domain analysis for time shifting with L=2 and L=3 symbols of PDCCH (dedicated)

7.25 In the hybrid approach the carriers of the low power and standard power cells are offset by 10MHz, and it was shown that the SCH and BCH channels in the central 6RBs do not interfere with each other. Taking this into account, Figure 70 shows how four low power and two standard power networks can co-exist using time shifting. The two standard power networks are assumed to be unconstrained and use the full three symbols of PDCCH (L=3). The two SP networks might represent a macro network and the SP licensee's own low power network, separate from those in the shared access channel.

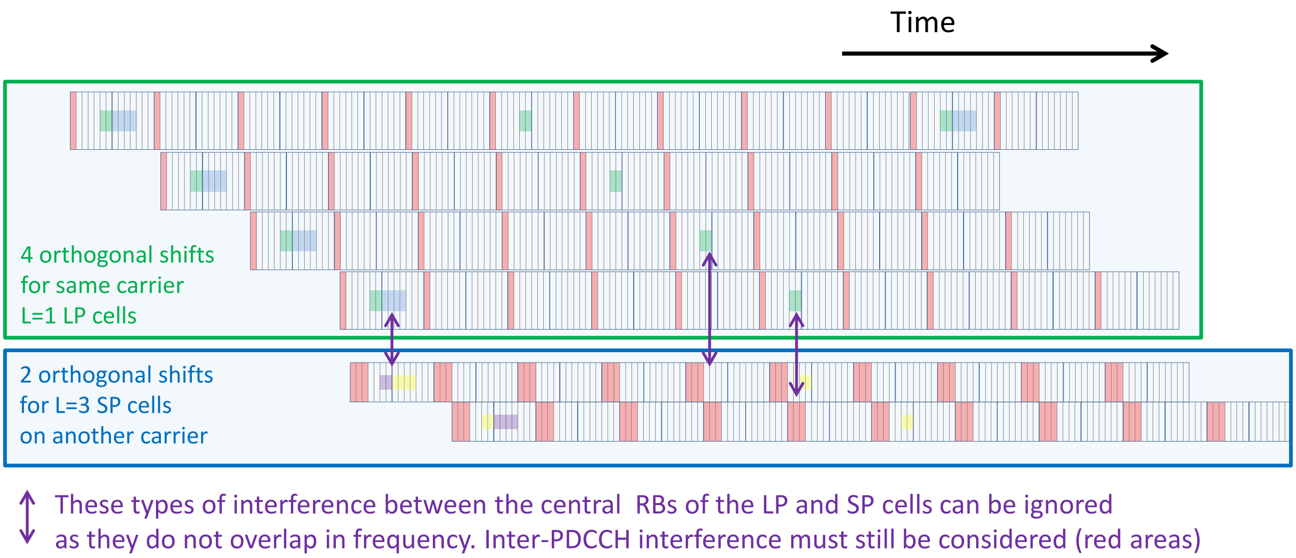


Figure 70 Co-existence of multiple L=1 low power cells, and two L=3 standard power cells in hybrid configuration

7.4.2 Carrier offsetting

7.26 It has been shown that time shifting could enable up to four cells on the same centre frequency to avoid simultaneous transmission of their control channels. Here we consider how carrier offsetting can be used to increase this number, by avoiding frequency domain overlap of the SCH and BCH transmissions.

7.27 In order to stay within the 20MHz channel bandwidth, carrier offsetting requires a reduction in bandwidth to 15MHz as illustrated in Figure 59. With 15MHz LTE, it may be possible to have up to 5 groups of cells sharing a 20MHz channel with their central 6 RBs on different frequencies. In practice, the different carriers may not be perfectly 'orthogonal', so some additional offsetting beyond 6RBs may be advisable. It may be more prudent to use only 3 or 4 carrier offsets with at least 7RBs between them.

7.28 The 15MHz needs slightly less 'guard RBs' at the edge of channel than the 20MHz LTE, which can either be used to increase the protection towards the SP network, or that between LP cells

7.29 The higher carrier offsets (towards the right on Figure 71) suffer less interference from the SP network as there is less overlap. Given then that some are better than others, carrier offsets per location could be allocated on a 'first deployed, first served' basis to stimulate rollout.

7.30 Within each carrier offset, time shifting could enable multiple cells per group. Time shifting is also needed to ensure the channel wide PDCCHs do not interfere on any of the overlapping spectrum. Figure 71 shows that all lower power and standard power cells have overlapping spectrum.

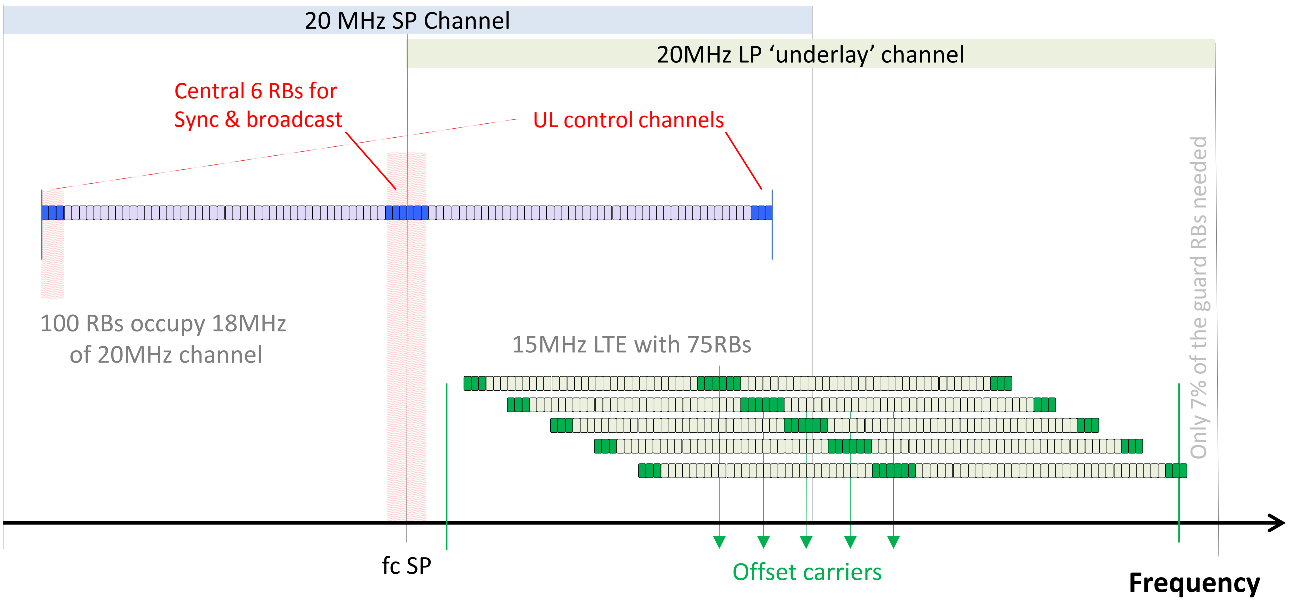


Figure 71 Carrier offsetting for the low power shared access cells

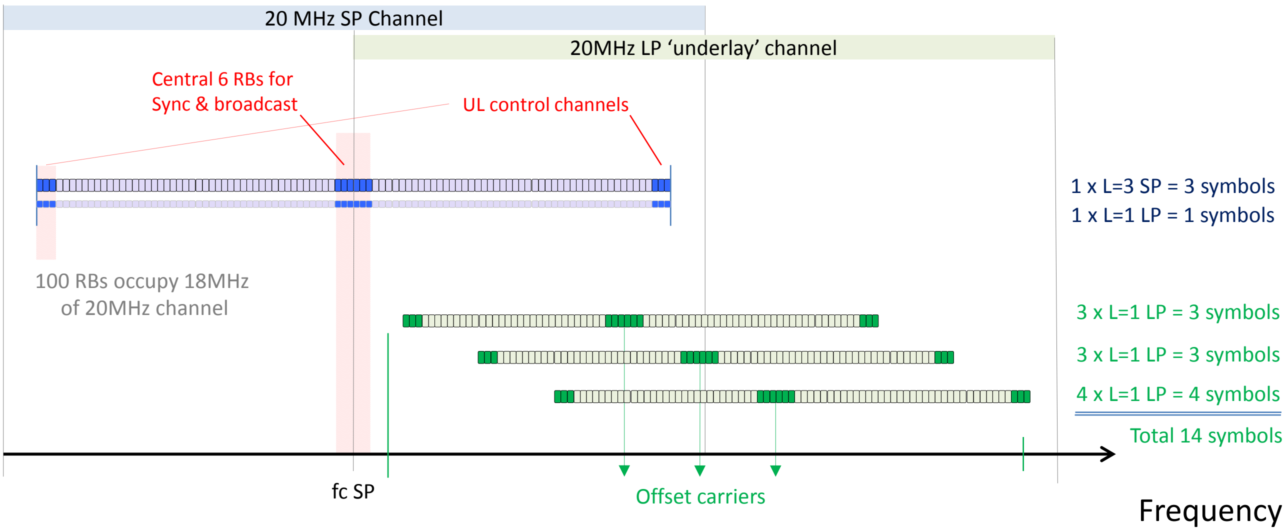


Figure 72 Combination of carrier offsetting and time shifting to enable two standard power networks and ten low power networks to operate in the hybrid configuration.

7.31 Figure 73 shows a possible solution to enable a total of 12 cells to operate in the hybrid configuration. In the standard power channel, there is one 20MHz L=3 cell (assumed to be a standard power macrocell) plus one L=1 cell (assumed to be the standard power licensee's own low power cell). There are then ten 15MHz low power networks spread across three carrier offsets in the lower power channel. In this plan, there are fewer time shifts in the lower carrier offsets, which compensates for the increased overlap, and thus interference with the Standard Power (SP) channel.

7.32 There may be many other ways to enable co-existence of multiple cells from different licensees, of which Figure 73 is just one example that demonstrates it is at least feasible.

7.33 This analysis considers how the SCH, BCH and PDCCH channels can be arranged in time and frequency to avoid transmission on the same resources. It has been shown that carrier offsetting can be used to provide protection for the SCH and BCH which are located only over the central 6RBs of the channel bandwidth. The PDCCH on the other hand occupies the whole bandwidth, and so only time domain shifting can protect this channel. Given that each cell must have a minimum of 1 symbol of PDCCH overhead during each sub-frame, and that there are 14 symbols in a sub-frame, then there is a fundamental limit of 14 cells that can operate with overlapping spectrum. This represents a hard limit for co-existing cells. Later we consider the 'soft' limit of the amount of resources there are left for user data as a function of the number of lower power licensees sharing the channel.

7.4.3 Frequency Partitioning

7.34 With frequency partitioning, each Low Power (LP) network gets its own dedicated 1.4MHz of spectrum, sufficient for a total of 6 RBs, as illustrated in Figure 73.

7.35 These 6 RBs occupy 6 x 180kHz = 1.08 MHz of their 1.4MHz channel, so the guard regions are distributed across the LP underlay channel. This creates a risk of interference from the lowest LP network to the central 6 RBs of the SP network, but time shifting could be used to avoid this. Care would also be needed to protect the Up Link (UL) control channels too

7.36 Note that the LP cells within the lower 10MHz 'overlap' will likely have lower performance than those in the upper 10MHz, as they will suffer more interference from the standard power network.

7.37 Performance of the LP cells will be much less than a 20MHz system, but this approach will definitely 'work' in a scenario with multiple co-located LP cells, so could be viewed as a fall back if other schemes fail.

7.38 Partitioning is envisaged to be a dynamically activated only in locations where other methods are not viablearises, and a single shared LP site is not an option. A single shared 20MHz LP site would give higher capacity than the 14 x 1.4 MHz cells as there would be less overhead.

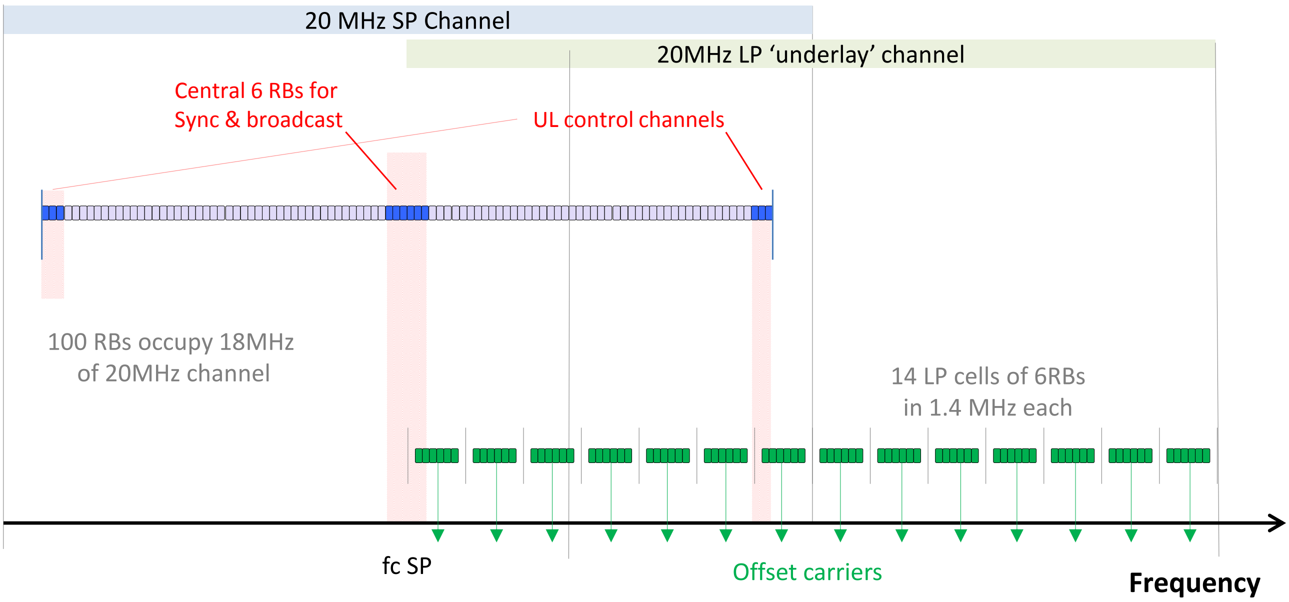


Figure 73 Frequency Partitioning of the LP underlay channel

7.4.4 Analysis of overheads with shared access

7.39 The multiple co-located licensees must all maintain the PDCCH control channel for their user terminals. It is assumed these must be protected by avoiding transmissions from other licensees during PDCCH transmissions. As such, the percentage of resources allocated to PDCCH increases with the number of LP licensees.

7.40 Figure 74 shows how the overheads are analysed for a given number of symbols occupied by the PDCCH, denoted as C. This includes explicit counting of the RS overhead, (denoted as R). User data occupies all resources not used by control or reference symbols, and are labelled D in the figure. The number of resource elements allocated to data and control are counted and summed, and the overhead evaluated. This is performed for 1,2…14 columns of PDCCH, which represents the overlapping regions of the shared spectrum.

7.41 The BCH and SCH occur once every ten sub frames, and represent less than 1% of the overhead, and so are assumed to be negligible [25].

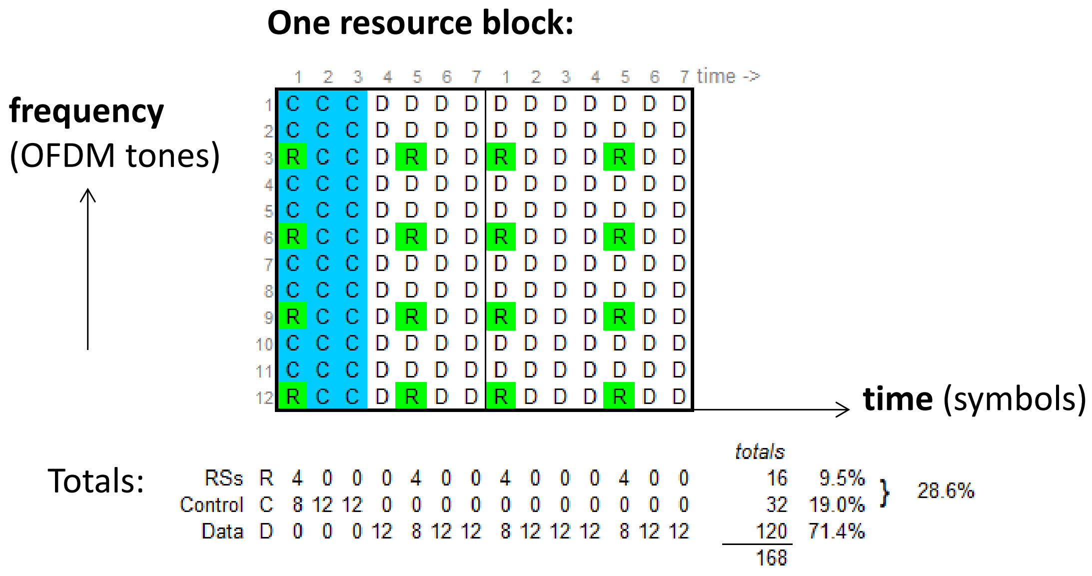


Figure 74 Example of overhead analysis for L=3 symbols of PDCCH

7.42 Figure 75 shows the percentage of resources available for user data in the low power shared access channel as function of the number of co-existing cells, for both the hybrid and dedicated schemes. Although it is feasible to have 14 low power operators in a dedicated channel, there would be no resource available for user data, and so this would not be a sensible operating condition.

7.43 In the hybrid case, the standard power network is assumed to be using the maximum L=3 symbols of PDCCH, as it is likely to be serving more user terminals with its wider coverage area. As a result, the overhead in the hybrid approach appears larger than in the dedicated case.

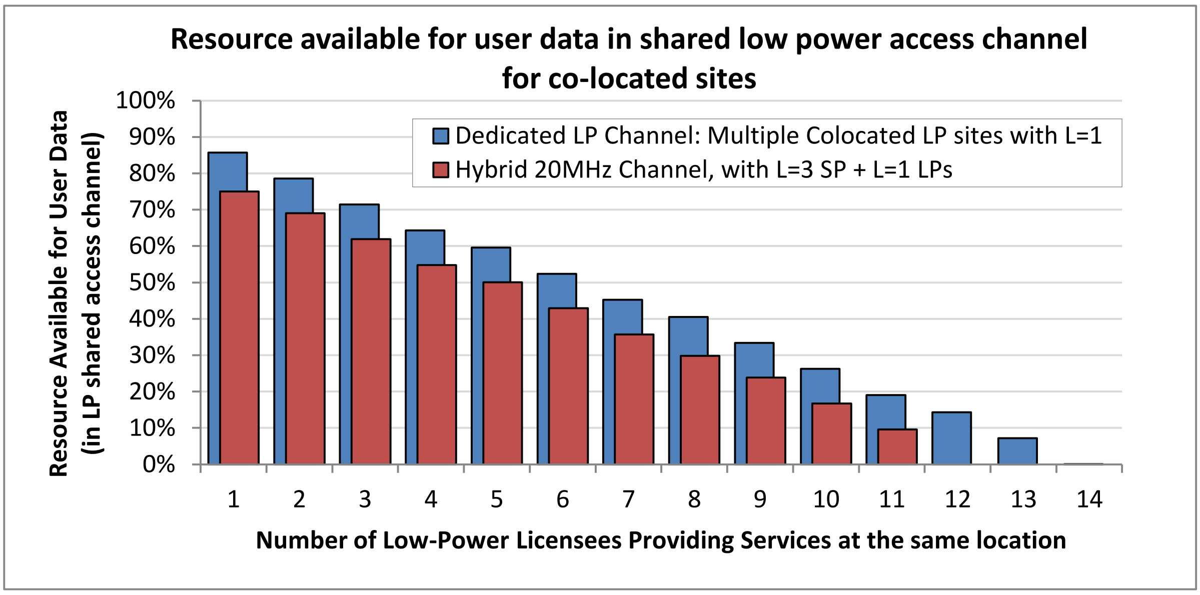


Figure 75 Resources available for user data in shared low power access channel for co-located sites.

7.5 Recommendations

7.44 Whilst there is no fundamental limit to the overall number of licenses that can be awarded for the low power shared access, there are limits on the number of cells from different licensees that can operate with overlapping coverage. In order that multiple licensees sharing overlapping spectrum can provide services over the same geographical area, the SCH, BCH and PDCCH control channels should be co-ordinated such that they are not transmitted on the same time and frequency resources.

7.45 The SCH and BCH channels are located within the central 6RBs of the carrier bandwidth, and so a combination of time shifting and/or carrier offsetting can be used to avoid transmission on the same resources.

7.46 The PDCCH is transmitted over the entire carrier bandwidth and so time domain shifting is needed to ensure these are not simultaneously transmitted on any cells sharing the same spectrum and geographical area.

7.47 There is a hard limit of 14 co-existing cells that can transmit in overlapping spectrum in the same geographical area whilst avoiding PDCCH transmissions at the same time. However, with this many cells, there would be no resources left for user data. Figure 75 shows the percentage of resources available for user data in the low power shared access channel as a function of co-located low power cells, which provides a soft limit.

7.6 Answers to study questions

Study Question	**Response**
Assess the maximum number of licences that could be issued for low-power shared access in 2.6 GHz spectrum, based on the following:	Limits apply only where multiple licensees wish to provide services over the same geographical area. There is no fundamental limit if licensees operate in mutually exclusive locations, e.g. in-store coverage of different retail chains.
• Assume that low-power licensees are required to agree a code of practice to manage situations where several or all of them are seeking to use the spectrum in a geographical area;	Low power licensees transmitting on shared spectrum should co-ordinate the timing and/or centre frequencies of their transmissions to ensure that their control channels (SCH, BCH and PDCCH) are not transmitted on the same time and frequency resources.
• Include the two scenarios of (a) 10 MHz low-power only and (b) hybrid approach of 10 MHz low-power and a further 10 MHz underlay;	Both hybrid and dedicated channelization plans are considered. In the hybrid approach, the carrier of the standard power network is offset by 10MHz which provides mutual protection of the SCH and BCH channels located at the centre of their bandwidths. It is assumed that the standard power network will need to use the maximum amount of L=3 symbols of PDCCH in order to potentially serve a large

	number of user terminals.
• Identify any limiting factors that place an absolute cap or significant constraint on the number of licences.	It is the bandwidth-wide PDCCH which provides a fundamental limit to the number of cells that can provide service to the same area. Assuming each cell uses the minimum of L=1 symbol of control per sub-frame, and there are 14 symbols per sub-frame, then the hard limit is 14 cells in shared spectrum providing services to the same geographical area. In practice there is also a soft limit of the amount of resources available for user data transmission as shown in Figure 75, for both the hybrid and dedicated approaches to shared spectrum

8 Appendix: Interference Criterion for Workpackages A and C

8.1 The questions posed in Chapter 3.2 and in Chapter 5 require a definition of a level of interference that would be acceptable at the victim receivers. For consistency, this level of interference was selected to be equal in the analyses presented in Chapter 3.2 and in Chapter 5.

8.2 In the remainder of this chapter the existing methodology on which the interference threshold can be based on is first described. Then the methodology steps that are required for the calculation of the interference threshold are analysed. Conclusions are drawn based on the key outputs from existing literature on the acceptable level of throughput degradation and interference at the end of this chapter.

8.1 Existing methodology for the definition of the interference threshold

8.3 The interference from a Frequency Division Duplex (FDD) Up Link (UL) channel to an adjacent channel FDD UL channel that is considered acceptable, has been investigated as part of the Long Term Evolution (LTE) standardisation process. Reference [9] examines the maximum allowable Adjacent Channel Interference Ratio (ACIR) for a particular throughput degradation, chosen as 10% throughput degradation for 5% of the users.

8.4 The above acceptable level of interference is suggested as the maximum allowable interference in the case of adjacent interference from a Time Division Duplex (TDD) to an FDD base station. Our proposed criterion for acceptable interference to LTE FDD is that it will be no worse than that interference that would normally be received from another network on an adjacent channel.

8.5 The following assumptions are made in this analysis:

- The ACIR is dominated by the User Equipment (UE) Adjacent Channel Leakage Ratio (ACLR) in the uplink [9].
- The network deployment is uncoordinated. The worst case interference arises when the aggressor base station is sited at the lowest Signal to Interference plus Noise Ratio (SINR) level of the victim. This results in the aggressor UE being located at cell edge and thus transmitting full power, but also located close to the victim eNodeB, so that the path loss between aggressor and victim is small.
- The aggressor UE transmits at full power.
- We consider the scenario where victim and aggressor are both 10MHz bandwidth, because the study [9] did not consider the 20MHz channel. We assume that the spectral density will be the same for systems with 20MHz bandwidth.

8.6 The steps in the methodology for the calculation of power (B) are:

8.6.1 The output of the coexistence study [9] for the particular scenario that we are interested in (uplink aggressor to uplink victim, urban clutter, 10MHz channel) is first read. The emission spectrum of aggressor UE into the adjacent channel is evaluated, based on the ACLR results from [9].

8.6.2 The emissions mask that leads to the desired level of throughput degradation is derived.

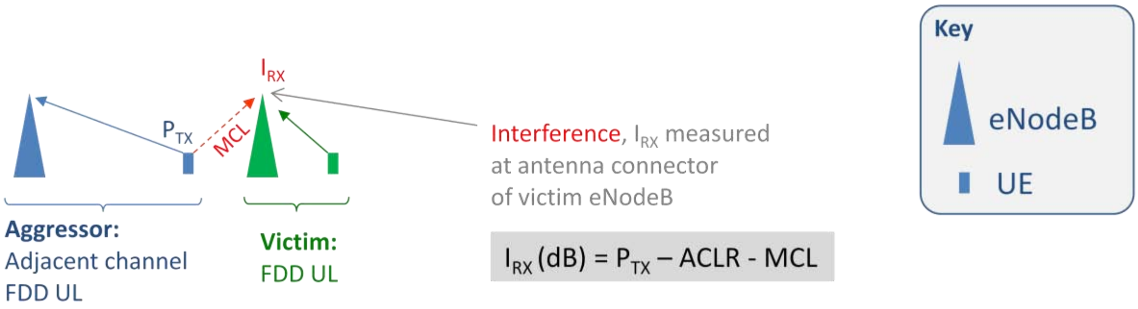


Figure 76 Scenario for evaluating the acceptable interference

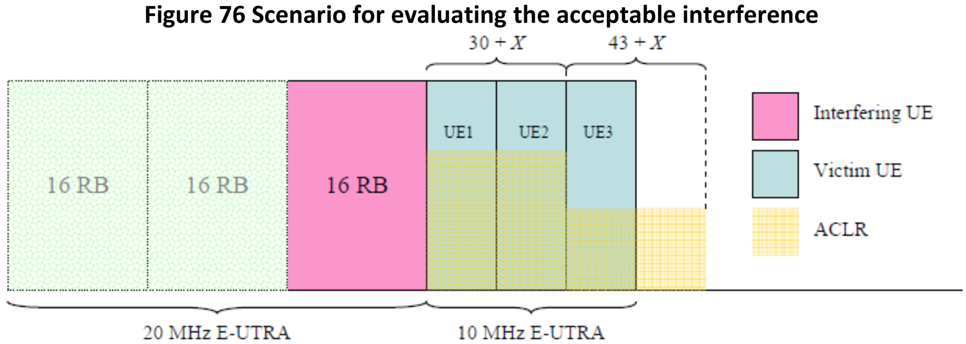


Figure 77 UE emission mask used in [9]. Note that in [9] the size of the Resource Block (RB) is 375kHz. Also note that the plot corresponds to 3 UE aggressors in a 20 MHz channel causing interference to the adjacent 10 MHz channel.

8.6.3 The above emission masks are used to calculate the corresponding level of adjacent channel interference. The interference from the worst case adjacent channel to the victim is evaluated.

8.6.4 The incident interference power to the victim eNodeB (at the antenna connector) is reduced by the Minimum Coupling Loss (MCL). MCL = 70dB for the simulations in [9].

8.7 Figure 77 plots a schematic of the calculation involved for the evaluation of the acceptable interference level. The UE emission mask that is suggested in [9] is plotted in Figure 78. The emissions follow a staircase- shaped reduction in power with frequency offset.

8.8 Note that in [9] the size of the Resource Block (RB) is 375kHz. The case of interest in Chapter 3.2 is for a 10 MHz/20MHz aggressor with a 10/20 MHz victim rather than the case illustrated

8.9 The steps above are analysed further in the next section.

8.2 Methodology

8.10 In this section we analyse each of the steps that lead to the definition of the acceptable level of interference in more detail.

8.2.1 Step 1: Determine the relevant result from the 3GPP study

8.11 The 3GPP technical report [9] provides several plots of the throughput degradation, for different scenarios. Having selected the most appropriate scenario (uplink aggressor to uplink victim, urban clutter, 10MHz channel), we calculate below the required ACIR offset.

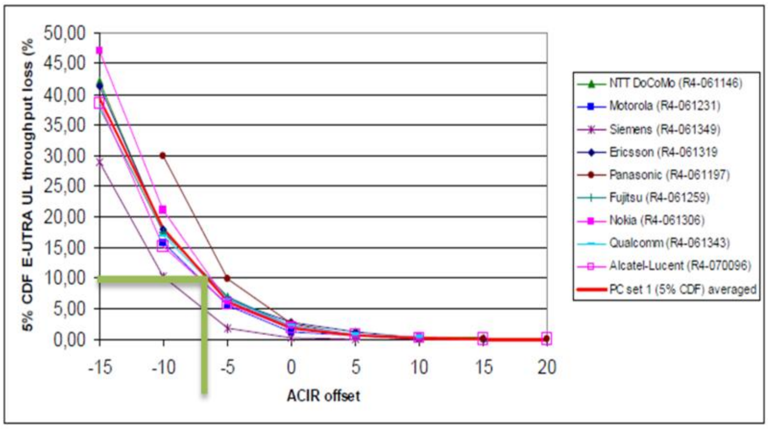


Figure 7.3e: 5% CDF E-UTRA uplink throughput loss for power control set 1

X	Y
-15	38.72
-10	17.90
-5	6.23
0	1.95
5	0.58
10	0.19
15	0.00
20	0.00

f(x) = a*exp(-((x-b)/c)^2)
a = 93.23
b = -28.42
c = 14.32
R-square: 0.9999

Figure 78 Fitting a function to the throughput loss results of [9]

8.12 The ACIR offset that leads to 10% throughput loss in 5% of the users is $X = -7\text{dB}$. This result was not impacted by the uplink power control scheme.

8.13 This offset, $X = -7\text{dB}$, should be applied to the [9] UE test mask. This output is for 10MHz. [9] did not consider interference in 20MHz channels.

8.14 Plots of the masks for 10 and 20 MHz channels are provided further below.

8.15 Figure 78 reproduces the plots of Figure 7.3e of [9]. It also provides with a table of plot-values that were read from the averaged curve labelled “PC set 1 (5% CDF) averaged”. Finally, Figure 78 provides a numerical function fitted to the table values. This model is used to derive the X value (the value in the x-axis of the plot) for which the throughput loss is 10% (10 on the y-axis).

8.2.2 Step 2: Derive the emission mask

8.16 In the previous step the UE emission mask parameter X was read from the results of [9] so that the throughput degradation in the network is 10% in 5% of the users. In this step the parameter $X = -7\text{dB}$ is used to derive the emission mask that lead to such throughput degradation.

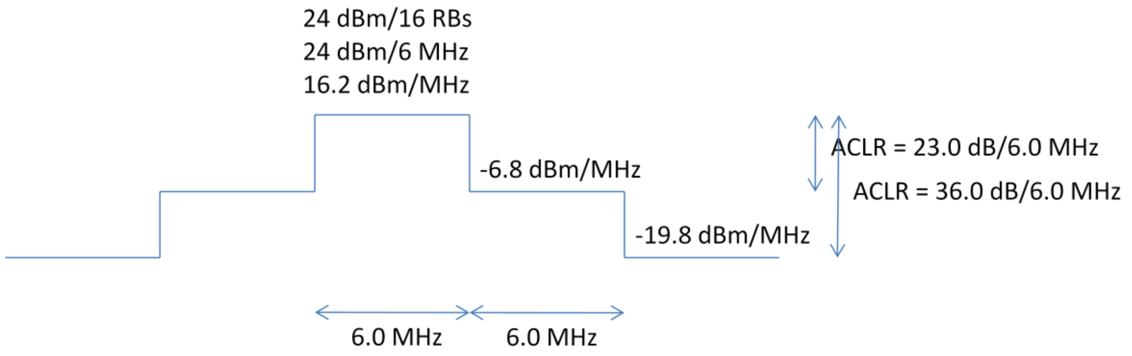


Figure 79UE mask corresponding to acceptable interference – 20 MHz

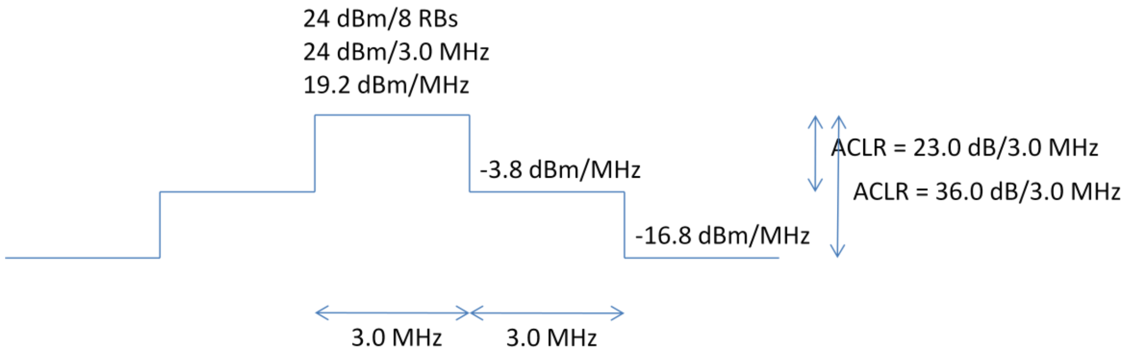


Figure 80UE mask corresponding to acceptable interference – 10 MHz

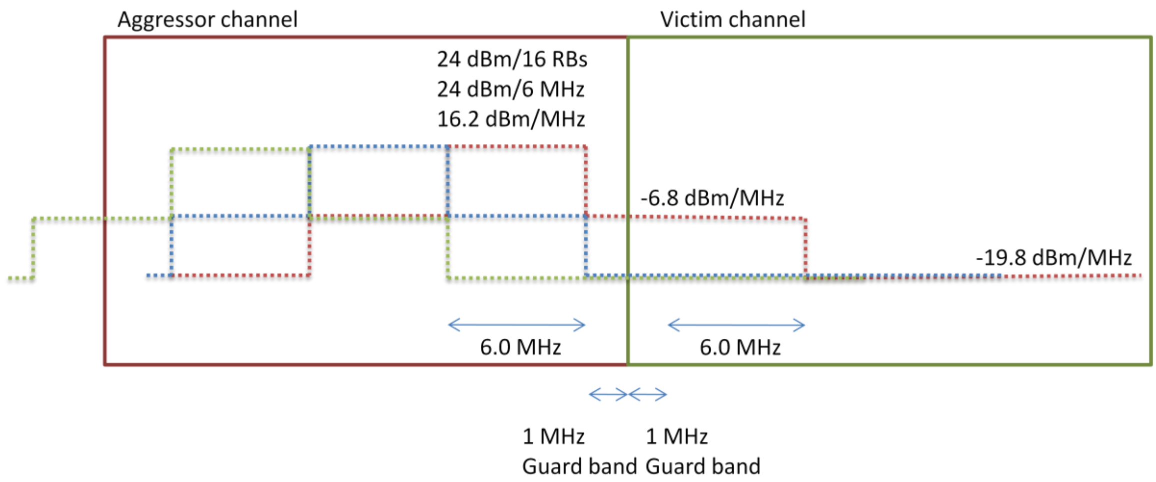


Figure 81Emission masks of the 3 aggressor UEs – 20MHz channel

8.17 Figure 79 and Figure 80 plot the mask for the 20 and 10MHz channels respectively, for $X = -7\text{dB}$. The shape of the UE emissions' mask is provided in detail in [9], for a variable parameter X. It is reminded herein that in [9] the size of the RB is 375kHz.

8.18 Figure 81 plots the emission mask that results from aggregating the separate emissions from 3 UEs in the aggressor channel, in the 20MHz channel.

8.19 Note that the -19.8dBm/MHz level extends on either side of the band. Also note that the aggregate interference at the victim channel comprises 3 separate UE out-of-channel emissions, which are plotted in the figure with 3 coloured dashed lines.

8.20 The UE in the top of the aggressor channel (red dashed line) contributes to the interference power with -6.8dBm/MHz over 6.0MHz interval, and with -19.8dBm/MHz over the 12MHz interval.

8.21 The other two UEs (blue and green dashed lines) contribute to the interference power at -19.8dBm/MHz over the 18MHz interval.

8.2.3 Step 3: Calculate the adjacent channel interference

8.22 In the previous step the UE emission mask parameter X was used to derive the mask properties that lead to the threshold throughput degradation. In this step the adjacent channel interference that is implied by employing this mask is calculated. The analysis considers both 10MHz and 20MHz channels.

8.23 Let A, B, and C the three spectral density levels in the derived UE emissions' mask, expressed in dBm/MHz. From the shape of the emissions' mask (see previous step) we derive:

$$\begin{aligned} A &= 24 - 10\log_{10}\mathrm{BW} \\ B &= A - (30 + X) \\ C &= A - (43 + X) \end{aligned} \quad (2)$$

where $\mathrm{X} = -7$dB, and BW is the UE emissions' bandwidth, given by:

$$\mathrm{BW} = \mathrm{BWch} \times (1 - \mathrm{GBpc})/3 \quad (3)$$

where $\mathrm{BWch} = \{10{,}20\}$MHz is the channel bandwidth, GB=10% is the guardband overhead, and the denominator value 3 corresponds to the UE count.

8.24 The interference power from the UE in the top of the aggressor channel (red dashed line in Figure 81) is given by:

$$I_1 = 10\log_{10}\left(\mathrm{BW}\times 10^{B/10} + (\mathrm{BWch}(1-\mathrm{GB}) - \mathrm{BW})\times 10^{C/10}\right) \quad (4)$$

8.25 The interference power from each of the other two UEs (blue and green dashed lines in Figure 81) is given by:

$$I_2 = C + 10\log_{10}\left(\mathrm{BWch}(1-\mathrm{GB})\right) \quad (5)$$

8.26 The aggregate interference power from all three UEs at the victim adjacent channel is given by:

$$I_3 = 10\log_{10}\left(10^{I_1/10} + 2\times 10^{I_2/10}\right) \quad (6)$$

which results in $I_3 = 2.5$dBm regardless of the channel bandwidth.

8.2.4 Step 4: Take into account the path loss between aggressor and victim

8.27 In the previous step the interference power that corresponds to 10% throughput degradation in 5% of the users was calculated, in the case of 10MHz aggressor into 10MHz victim, and 20MHz aggressor into 20MHz victim channels. In this step this calculated interference power is adjusted for the path loss between the aggressor and victim.

8.28 The interference power threshold that leads to the threshold throughput degradation is given by:

$$I = I_3 - \mathrm{MCL} \tag{7}$$

where $\mathrm{MCL} = 70\mathrm{dB}$ is the MCL. Note that the MCL includes all propagation losses (e.g. median path loss model, antenna pattern, antenna gain, connector losses, etc.).

8.29 The interference power that leads to 10% throughput degradation in 5% of the users is $\mathrm{I} = -67.5\mathrm{dBm}$, regardless of the channel bandwidth.

8.3 Conclusion

8.30 In this chapter we provided an analysis of the definition of a level of interference that would be acceptable at the TDD victims' receivers. This analysis is used in Chapter 3.2 and in Chapter 5.

8.31 The interference power that leads to 10% throughput degradation for 5% of the users is $-67.5\mathrm{dBm}$. This threshold is suggested as the maximum allowable interference in Chapter 3.2, adjacent interference power from a TDD to an FDD base station, and in the uplink interference threshold in Chapter 5.

9 Abbreviations

3G	3^{rd} Generation
3GPP	3rd Generation Partnership Project
4G	4^{th} Generation
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio
BCH	Broadcast Channel
BEM	Block Edge Mask
BS	Base Station
BW	Band Width
CEPT	European Conference of Postal and Telecommunications Administrations
CIR	Carrier to Interference Ratio
CL	Coupling Loss
DL	Down Link
EC	European Commission
EIRP	Equivalent Isotropically Radiated Power
FDD	Frequency Division Duplex
IQ	In-phase/Quadrature
ISD	Inter Site Distance
LABS	Local Area Base Station
LP	Low power
LPBS	Low Power Base Station
LPUE	User Equipment in the Low Power channel
LTE	Long Term Evolution
MCL	Minimum Coupling Loss
NLOS	Non Line Of Sight
OFDM	Orthogonal Frequency-Division Multiplexing
PA	Power Amplifier
PDCCH	Physical Downlink Control Channel
PDCCH	Packet Data Control Channel
PDSCH	Physical Downlink Shared Channel
PFICH	Physical Control Format Indicator Channel
PHICH	Physical Hybrid ARQ Indicator Channel
PLL	Phase Locked Loop
RB	Resource Block
RF	Radio Frequency
RS	Reference Signals
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCH	Synchronisation Channel
SINR	Signal to Interference plus Noise Ratio
SP	Standard Power
SPBS	Standard Power Base Station
TD	Time Division
TDD	Time Division Duplex
TLC	Technical Licence Conditions
TX	Transmitter
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunications System

WiMax	Worldwide Interoperability for Microwave Access
WINNER	Wireless World Initiative New Radio

10 References

[1] GSMA, "The 2.6GHz spectrum band - An opportunity for Global Mobile Broadband", http://www.gsmamobilebroadband.com/upload/resources/files/23092010131807.pdf, September 2010.

[2] Real Wireless 4G Blog www.realwireless4g.wordpress.com

[3] "Final Report: Low power shared access to spectrum for mobile broadband", Real Wireless, March 2011. Available from http://stakeholders.ofcom.org.uk/consultations/combined-award/

[4] "Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues", Ofcom consultation, 22nd March 2011. Available from http://stakeholders.ofcom.org.uk/consultations/combined-award/

[5] European Commission Decision of 13 June 2008 on the harmonisation of the 2 500-2 690 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community (2008/477/EC), from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:163:0037:0041:EN:PDF

[6] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception. Technical Specifications TS 36.101 version 10.2.1, 3rd Generation Partnership Project (3GPP), 2011

[7] CEPT Report 019, Least restrictive technical conditions for WAPECS frequency bands, 2008.

[8] "Award of available spectrum: 2500-2690 MHz, 2010-2025 MHz", Ofcom Information Memorandum, 4 April 2008. Available from http://stakeholders.ofcom.org.uk/consultations/2ghzrules/statement/im/

[9] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios. Technical Report TR 36.942 version 10.2.0, 3rd Generation Partnership Project (3GPP), 2011

[10] IST-2003-507581 WINNER.Final report on link level and system level channel models.Technical report, Sep. 2003.

[11] "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz", ITU-R Recommendation P.1411-4, 2009. Available from http://www.itu.int/rec/R-REC-P.1411-5-200910-I/en

[12] Saunders, S., Aragon, A. Antennas and Propagation for Wireless Communication Systems, Second Edition, John Wiley & Sons

[13] 3GPP LTE Standard TS36.104, v10.1.0. Available from http://www.3gpp.org/ftp/specs/html-info/36104.htm

[14] Analog Devices inc, "ADF4602: Single-Chip, Multiband 3G Femtocell transceiver", 2011. Available from http://www.analog.com/en/rfif-components/rfif-transceivers/adf4602/products/product.html

[15] Avago Technologies inc, "ACMD-6007 LTE Band 7 Duplexer", 2010. Available from http://www.avagotech.com/pages/en/rf_microwave/fbar_filters/duplexer/acmd-6007/

[16] A. Ghorbani, and M. Sheikhan, "The effect of Solid State Power Amplifiers (SSPAs) Nonlinearities on MPSK and M-QAM Signal Transmission", Sixth Int'l Conference on Digital Processing of Signals in Comm., 1991, pp. 193-197.

[17] Simulink by The Math Works. Available from http://www.mathworks.com/products/simulink/

[18] Trans Tech inc, "Coaxial Resonator Filter Tool (CRaFT)", 2007. Available from http://www.trans-techinc.com/documents/craft_program.pdf

[19] "SEAMCAT implementation of Extended Hata and Extended Hata-SRD models", http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v1.pdf

[20] COST231 final report, COST Action 231: Digital Mobile Radio Towards Future Generation Systems, European Commission / COST Telecommunications, Brussels, Belgium, 1999.

[21] "Guidelines for evaluation of radio interface technologies for IMT-Advanced", ITU-R M.2135, 2008

[22] S.Sesia et al, "LTE the UMTS Long Term Evolution", Wiley 2009, pp469

[23] "FDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis", 3GPP document TR 36.921, 9.0.0, 2010-04-06

[24] "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation", 3GPP document TS 36.211 8.9.0, 2009-12-16.

[25] "Summary of Downlink Performance Evaluation", 3GPP R1-07257, 2007