Final Report for the WiMAX Forum

Cross Border Trigger Limits and Case Study for TDD/FDD Border Coordination in Europe

14 April 2009

QPJA002C

analysys mason

Contents

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1 Executive summary

This document is the final report of a study carried out by Analysys Mason on behalf of the WiMAX Forum, to examine cross border coordination between Frequency Division Duplex (FDD) and Time Division Duplex (TDD) systems in the 2500-2690 MHz frequency band in Europe.

Throughout the remainder of this study, FDD refers to the Universal Mobile Telecommunications System (UMTS), developed by 3GPP and TDD refers to Worldwide Interoperability for Microwave Access (802.16e) developed by IEEE.

This report describes a two-phase study into requirements for coordination of TDD WiMAX to TDD WiMAX; TDD WiMAX to UMTS and UMTS to TDD WiMAX networks in European border areas, and the appropriate level of field strength limit that should apply for the purposes of regulatory coordination of systems being deployed in the 2.6 GHz frequency band.

Our approach to the study was to break the analysis into two distinct phases of interference modelling.

► *Phase one modelling*

The first phase of the study consisted of a single interferer-victim path using smooth earth curves in urban, suburban and rural environments. In this phase we consider a single interferer. The objective was to **review the trigger values proposed in the European recommendation for 3G cross border coordination, which is ECC Recommendation (01) 01.** This phase included preparation of link budgets and required Carrier to Interference (C/I) ratios for each technology. Key link budget parameters were used, along with propagation prediction based on Recommendation ITU-R P.1812[1] to explore the impact of a range of **trigger values** on both the interfering and victim links.

The modelling in this phase was completed with Microsoft Excel.

► *Phase two modelling*

The second phase of the study consisted of several European cross-border scenarios, and considered many (typically one million) interferer-victim paths, representative of deployment scenarios that might occur in practice in European border areas. This phase of modelling also used the propagation model Recommendation ITU-R P.1812, as implemented within the ATDI ICS Telecom radio modelling tool.

1 ECC Recommendation (01)01 specifies use of propagation models ITU-R P.1546 and P.452 (where terrain detail is available). Our initial analysis for this study was conducted using these propagation models. Both phases of our analysis were subsequently updated to use the new ITU-R P.1812 model. The most recent ATDI ICS Telecom implementation of P.1812, updated for this study, has been used throughout our analysis. ATDI's implementation of the P.1812 model has validated against a second independent implementation of ITU-R P.1812, provided by BT.

In this phase of modelling, we considered the aggregated interference power of many interferers. The objective was to determine the **impact on network deployment in border areas.** This was explored in the form of a European case study, based upon the Basle and Maastricht border regions. Combinations of WiMAX Handheld, WiMAX Notebook and UMTS High Speed Packet Access (HSPA) coverage were analysed.

Within the ECC recommendation, we have noted that the suggested trigger value of 21dBμV/m/5MHz is specified per base station, per carrier. This suggests that no single interferer is permitted to exceed that threshold. In practice, in assessing real network deployment, there will typically be many simultaneous interference paths and the interference that a victim base station needs to tolerate is the aggregation of all sources of interference. The number of interferers that make a **significant contribution** varies from scenario to scenario, but can be as few as one, two or three interferers; typically, the closest interfering base stations to the test point. For this reason, in Phase 2 of our analysis we have considered how the aggregated sum of interference from typical network deployments compares to the suggested threshold.

The modelling in Phase 2 was completed with ATDI ICS Telecom version 9.1.4 with an appropriate terrain and clutter database. Results where analysed with the aid of an SQL database.

Our detailed analysis of link budgets, propagation and interference effects has led us to the conclusion that in order to **protect** TDD victim base stations, the **aggregated** interference predicted at test points 3m above the border should be no more than **30dBμV/m/5MHz**.

This aggregated limit could be achieved by any number of combinations of interferers; a small number of examples is shown below:

- Sum[2] of eight interferers, each measuring 21dBμV/m at the test point
- Single interferer measuring 30dBμV/m at the test point
- Sum[2] of two interferers, each measuring 27dBμV/m at the test point
- Sum[2] of two interferers, measuring 29 and 23dBμV/m at the test point respectively.
- Sum[2] of four interferers, each measuring 24dBμV/m at the test point
- Sum[2] of four interferers, measuring 25,24,24 and 22dBμV/m at the test point respectively
- Sum[2] of eight interferers measuring 22, 22, 22, 21, 20, 20, 20 and 20dBμV/m at the test point respectively
- The Bonn summation of any number of interferers, the most significant measuring 26dBμV/m at the test point respectively and the remainder measuring 20BμV/m or less at the test point.
- The Bonn summation of any number of interferers, the most significant measuring 22, 22, 22 and 21dBμV/m at the test point respectively and the remainder measuring 20BμV/m or less at the test point.

We have found that the use of the suggested coordination trigger level of **21dBμV/m/5MHz** per base station per carrier, as specified in the ECC Recommendation, would require many base

2 In these examples, both the power sum and the Bonn summation methods give the same result, as each interferer contributes 0.5dB or more to the result.

stations in the above examples to be subject to a coordination process. This is despite the fact that all examples that we have assessed, as described above, produce approximately the same aggregated level of interference. Thus, we conclude that an aggregated trigger value appears to be a more suitable parameter to use in cross border coordination, and it would be useful to have reference to this included in the relevant ECC cross border agreements for practical network implementation.

We have found that the Bonn power summation method (as described in this report) gives a more meaningful prediction than a simple power sum, since it excludes interferers that make an insignificant contribution to the interference. Using the Bonn summation method, we found that there is rarely a need to consider more than eight interfering base systems when calculating the aggregated interference at a test point. The simpler power sum method assumes that all sources of interference accumulate (in phase), and therefore each contributes to the aggregated result, which will not occur in practice due to phase differences. The Bonn summation method is used in several international coordination agreements, including those for T-DAB and DTT.

From our analysis within this study, which has considered both single entry interference (i.e. base station to base station), as well as the impact of coordination in real world scenarios, we conclude that more practical international coordination thresholds (specified at 3m above ground level) for TDD networks would be as follows:

- WiMAX TDD to WiMAX TDD: without synchronisation and without coordinated cross border fractional frequency re-use: **30dBμV/m/5MHz**
- WiMAX TDD to WiMAX TDD: with synchronisation: **58dBμV/m/5MHz**
- WiMAX TDD to WiMAX TDD: with coordinated cross border fractional frequency re-use: **65dBμV/m/5MHz** on preferred sub-carriers; **30dBμV/m/5MHz** on non-preferred carriers
- UMTS HSPA to WiMAX TDD **30dBμV/m/5MHz**
- WiMAX TDD to UMTS HSPA **14dBμV/m/5MHz.** (UMTS being more sensitive to interference)

In all cases the Bonn power sum of predicted interference is to be compared with the coordination trigger threshold at a series of 3m high test points located along the international border, spaced at 1km, using Rec. ITU-R P.1812 and an appropriate terrain database.

Note: 30dBμV/m/5MHz is equivalent to 33dBμV/m in a typical 10MHz WiMAX channel.

Definition of terms

International Coordination: A process that countries are obliged to follow should exported interference exceed the relevant **International Coordination Trigger Threshold.** The trigger threshold is typically elevated when the interferer uses specific channels or channel codes allocated to that country.

Interference Mitigation Techniques: These are techniques a potential interferer can apply to their own network in order to not exceed the **International Coordination Trigger Threshold**, or to minimise the impact of any breach of this threshold. Many of the same techniques can also be used to 'harden' a network against incoming interference.

Interference Coordination: A process by which two or more administrations achieve a mutually acceptable outcome with respect to international interference. In the best examples, coordination can result in a smooth transition of coverage in the border region and support roaming, or even handover, from one network to another. However, the process can be time consuming. When there is a mixture of TDD and FDD the issues may not be symmetrical, i.e. only one party may suffer from base station to base station interference.

2 Introduction

This report has been prepared by Analysys Mason Limited (Analysys Mason) on behalf of the WiMAX Forum, and provides the final report of a two-phase study into requirements for coordination of WiMAX and UMTS networks in European border areas in the 2.6 GHz frequency band, and the appropriate level of field strength limit that should apply for the purposes of coordination.

Taking account of the possibility of flexibility in assignment of paired and unpaired spectrum in the 2.6 GHz band in different countries in Europe, the purpose of this study is to consider appropriate field strength trigger values for cross border coordination requirements in the 2.6 GHz band in border areas in terms of both:

- Coordination between WiMAX networks in neighbouring countries (i.e. TDD-TDD co-channel coordination)
- Coordination between a WiMAX network in one country and a UMTS network in a neighbouring country (i.e. TDD-FDD co-channel coordination).

2.1 Background to the Study

The 2.6 GHz frequency band covers radio spectrum from 2500 – 2690MHz. The ITU World Radio Conference in 2000 (WRC-2000) identified this band as expansion spectrum for International Mobile Telecommunications (IMT), for countries wishing to implement this. IMT encompasses various wireless technologies, including WiMAX and 3G mobile technologies in Europe (e.g. WCDMA).

The 2.6 GHz band is therefore one of the key bands of interest to vendors and operators for the introduction of mobile WiMAX networks, based upon its potential availability in Europe and around the world, as well as the bandwidth that is available, which is particularly suited to delivery of high capacity wireless broadband services.

In Europe, the Electronic Communications Committee (ECC) initially designated the 2.6 GHz band as expansion spectrum UMTS/WCDMA systems, and associated ECC Decisions and Recommendations for the 2.6 GHz band specified a framework based upon use of the band for UMTS/WCDMA. ECC Decision (05)05 specifies a fixed designation of paired and unpaired spectrum, as illustrated in Figure 2.1.

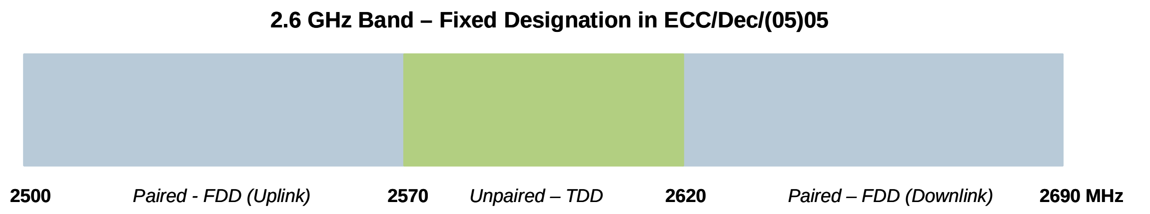

Figure 2.1: Fixed paired and unpaired blocks in the 2.6 GHz band [Source: Analysys Mason]

In line with regulatory policy to enable greater flexibility in spectrum use, the European Commission is promoting development of a more technical neutral regulatory framework for electronic communications through the WAPECS[3] initiative. This has implications on how the 2.6 GHz band might be allocated and used in Europe, since the WAPECS initiative moves away from fixed designation of spectrum for particular technologies. The EC has also developed a mandatory Decision on the 2500-2690 MHz band that suggests a greater flexibility in paired and unpaired spectrum designation than that contained within the ECC(05)05 decision. The EC Decision suggests that, based upon market demand, additional unpaired spectrum, suitable for WiMAX use can be allocated, whilst still maintaining the 120 MHz duplex split required for FDD systems, as illustrated in Figure 2.2. This shows an illustrative example of the possibility of assigning additional unpaired blocks below the top of the band, and below the 50 MHz centre gap, whilst maintaining the underlying 120 MHz fixed duplex separation for paired blocks.

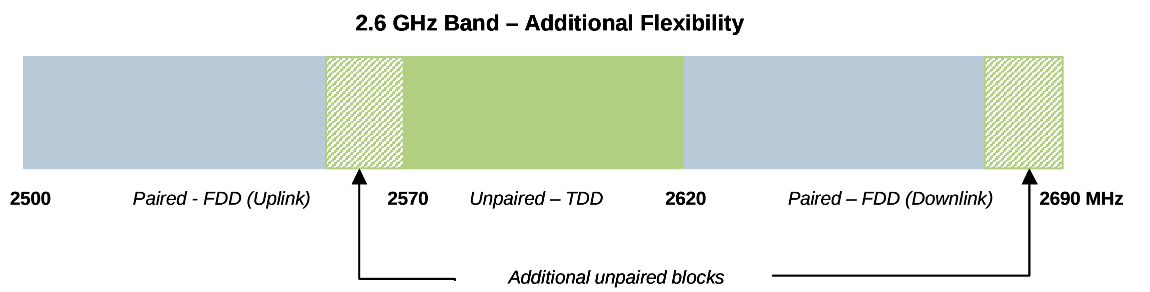

Figure 2.2: Possible flexible 2.6 GHz band plan [Source: Analysys Mason]

As a result of the EC developments, many European regulators planning to award new licences for use of the 2.6 GHz band are choosing not to implement ECC Decision (05)05, and are planning award processes based upon service and technology neutrality.

One implication of this flexibility is that it could result in different divisions between paired and unpaired blocks being implemented in different European countries, depending on demand for licences in different countries. A consequence of this is that there could therefore be a requirement

3 Report from CEPT TO THE European Commission in response to the Mandate to develop least restrictive technical conditions for frequency bands addressed in the context of WAPECS (Editorial revision 17 March 2008).

to co-ordinate networks of different types (e.g. FDD and TDD) operating in border areas of neighbouring European countries.

Cross border coordination is typically defined as a licensing requirement upon European operators when rolling out wireless networks in border areas. The requirement arises due to the proximity of different European countries to one another, in order to avoid interference between networks licensed to use the same frequencies in different countries.

In the case where different countries deploy the same band plan (e.g. the fixed band plan as illustrated in Figure 2.1), cross border coordination usually involves coordination between operators deploying the same type of system on different sites of the border (e.g. FDD-FDD or TDD-TDD). Greater flexibility in spectrum use, such as depicted in Figure 2.2, could result in mixed technology coordination being required (e.g. TDD-FDD) in addition to TDD-TDD and FDD-FDD.

With this in mind, the WiMAX Forum wished to commission a study to assess the requirements for cross border coordination of networks using the 2.6 GHz frequency band in Europe, particularly in light of potential greater flexibility in assignment of paired and unpaired blocks and the additional coordination scenarios that will result.

The objective is to propose an appropriate trigger value that provides equitable protection from interference for operators on both sides of the border, whilst also aiming to reduce the level of regulatory coordination required, by setting an appropriate ‘trigger value’ for coordination (measured as a field strength, in dBμV/m).

2.2 Structure of document

The remainder of this document is laid out as follows:

- Section 3 describes our approach to the study
- Section 4 describes our review of cross border coordination requirements in the 2.6 GHz band
- Section 5 assesses the applicability of ECC (01)01 trigger values to mixed technology scenarios
- Section 6 provides the review of 2.6 GHz cross border trigger values conducted for Phase 1 of this study
- Section 7 provides conclusions from Phase 1 of the study and Recommendations from Phase 2 of the study, and our overall findings from both phases of the work.

The report includes a number of annexes containing supplementary material:

- Annex A provides the link budget for HSPA
- Annex B provides the link budget for WiMAX.

3 Why is Cross Border Coordination Important for Deployment of 2.6 GHz Networks in Europe?

3.1 Introduction

Auctions are now underway, or planned, to award licences for use of the 2500 – 2690 MHz band in a number of European countries. This follows extensive study of deployment scenarios and frequency plans for higher bandwidth mobile and wireless broadband systems in the 2.6 GHz band, following the identification of the band as a key expansion band for International Mobile Telecommunications (IMT) at the ITU World Radio Conference in 2000.

Since the WRC-2000 decision was taken, 3G services have been widely introduced across Europe in the 2.1 GHz band, and the mobile market is now focused on optimising data delivery and looking beyond the current generation of 3G systems. Migration to an all-IP infrastructure, used by technologies such as WiMAX, LTE and HSPA+, is likely to result in greater variety of data services, as well as increasing diversity in wireless access technologies. It is this increasingly diverse range of data services that many industry players view will be deployed in the 2.6 GHz spectrum. The diversification in usage of spectrum designated for mobile communications is also encouraged by the European Parliament’s commitment to achieving increased flexibility in spectrum use, and technology neutrality in national frequency licensing frameworks, encouraged by the EC Radio Spectrum Policy Group (RSPG) WAPECS initiative.

Since WRC-2000, European regulators have studied a range of issues associated with making the 2.6 GHz band available for mobile services, including paired and unpaired band plan arrangements and co-ordination of frequencies in border areas. While early European decisions created a fixed division between paired and unpaired frequency blocks based on likely use, most regulators in Europe are now implementing a more flexible approach to awarding this spectrum based on market demand, as described in the introduction to this report.

The WiMAX Forum has subsequently identified the 2.6 GHz band as a preferred band for mobile WiMAX deployment, and since WiMAX is a TDD technology, this may drive demand for unpaired spectrum.

As a result of these developments, the mandatory EC Decision now in place relating to the 2.6 GHz frequency band allows more flexibility in allocated unpaired spectrum lots within the 2500-2690 MHz compared to the original ‘fixed’ band plan of ECC/DEC/(05)05.

However, whilst this enables greater flexibility in the division of paired and unpaired spectrum, the basis for coordinating networks in border areas for mixed (FDD/TDD) technology scenarios has not been studied in detail, which forms the background to the WiMAX Forum’s requirements to conduct this study. A trigger value of 21 dBµV/m/5MHz at 3m above ground level per carrier has been proposed as the basis of cross border operating agreements for uncoordinated TDD networks, compared to a value of 37 dBμV/m/5MHz for 'same technology' FDD (WCDMA-WCDMA). Whilst this forms a useful starting point as the basis for bilateral agreements to be negotiated between neighbouring countries, the appropriate trigger value to be applied in TDD-TDD and TDD-FDD coordination scenarios has not been fully studied, and it is possible that the value proposed might act as a constraint upon effective network deployment in border areas. The purpose of this study is therefore to provide an evaluation of an appropriate field strength trigger value for TDD-TDD (and TDD-FDD) network coordination in European border areas.

3.2 Why is Frequency Coordination Necessary in European Border Areas?

Cross border coordination is an important regulatory consideration within Europe due to the number of country borders that exist in the European area, particularly in central Europe. Given the proximity of wireless networks operating on both sides of the border, there is a potential for networks using the same frequencies in different countries to interfere in border areas where coverage areas are either close, or in some cases might overlap. Whilst bodies such as the CEPT provide recommendations on frequency allocation, it is up to the national regulator in each country to licence specific frequency bands according to national demand. As a result, networks in different European countries may be licensed to use the same frequency block for quite different technologies with, for example, different duplex methods (TDD versus FDD).

Cross border interference particularly causes problems in mobile networks in border areas when subscriber terminals might unintentionally 'roam' on to the network in a neighbouring country, if a base station of the neighbouring network is more visible to the terminal than the nearest base station of its home network. This unintended international roaming (e.g. a subscriber's handset connecting to the network of an operator in a neighbouring country rather than its home country) can create additional roaming charges, which is undesirable both to the subscriber, and to the network operator.

The purpose of cross border coordination is to coordinate the deployment of base stations of networks that are licensed to use the same frequencies in different countries. The approach taken to coordinating mobile systems in border areas in Europe is based on co-ordinating base stations, rather than mobile stations, since the base station location is fixed and can therefore be notified to the regulator and operators in a neighbouring country for co-ordination, where required. It is noted that the co-ordination between base stations of mobile systems implicitly helps to protect mobile stations, since resolving base station-base station interference will also reduce the interference to mobile stations. Recommendations, such as ECC Recommendation 01-01 (for mobile systems in the 2 GHz and 2.6 GHz bands), are explicitly written on the basis of co-ordination of the predicted field strength of each carrier produced by a base station not exceeding a certain limit[4].

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4 E.g. the following is an extract from ECC Recommendation 01-01, "Frequencies for UMTS FDD systems using preferential codes with centre frequencies aligned… may be used without coordination with a neighbouring country if the predicted mean field strength of each carrier produced by the base station does not exceed a value of …"

In some cases, the network operator might hold licences in different countries, in which case the coordination requirement is simplified and that operator is able to provide a contiguous service across borders. In most cases, however, different operators are licensed to use the same frequencies in different countries, meaning that coordination of the rollout of sites in border areas is required to avoid co-channel interference occurring.

Where frequency blocks have been licensed in a similar way in both countries, and operators are using the same technologies on both sides of the border (e.g. UMTS-UMTS), the cross border interference problem manifests as the base station from the network on one side of the border exceeding that of the network in the other country, causing terminals of subscribers of the latter network to roam on to the former. In the case where frequency blocks might not be assigned in a similar way across borders (e.g. in the case of a flexible use of the 2.6 GHz band), mixed technology scenarios can also occur (e.g. TDD-FDD), which means that additional cross border interference scenarios can occur, specifically:

- A TDD base station on one side of the border interfering with an FDD base station using the same frequency on the other side of the border, or vice versa
- A TDD base station on one side of the border exceeding the field strength of an FDD network on the other side of the border, causing the FDD subscriber to lose coverage, or vice versa.

In both cases, FDD and TDD networks are using the same frequency, but in different countries. The coordination problem then depends on the respective operators coordinating their sites in border areas to ensure that sufficient isolation exists between respective sites, or a minimum separation distance is adhered to. To enable the coordination of sites in border areas, the method normally used by European regulators and operators is to determine a maximum permitted field strength, which networks are not permitted to exceed without triggering a requirement for coordination with the network(s) in a neighbouring country. In practice this means that, assuming operators deploy sites that remain below the maximum permitted field strength, networks can be rolled out without triggering a coordination requirement. In the event that the network wishes to deploy sites that exceed the trigger value, coordination is required, and the operator must seek approval to deploy the relevant sites with the operator(s) in the neighbouring countries prior to the sites being deployed.

3.3 Cross Border Coordination in the 2.6 GHz Band

To manage potential interference between networks in border areas, the normal method used by regulators in Europe is to define bilateral coordination agreements that form part of the licence issued to the relevant operators for use of the frequencies concerned. These bilateral agreements are often based on pan-European recommendations using studies conducted within the CEPT.

Agreements are most often based upon the definition of field strength trigger limits, which triggers coordination being required between neighbouring countries if a network exceeds the trigger value.

For the 2.6 GHz band, ECC Recommendation 01-01 states that, for TDD systems with centre frequencies aligned, the base station field strength level at 3m height above ground level at the border of the neighbouring country should not exceed 21 dBμV/m/5MHz at and beyond the international border for ‘non preferential codes’ compared to 37 dBμV/m/5MHz at and beyond the international border for ‘preferential codes’[5]. This recommendation was developed in 2001, at a time when it was assumed that networks using the 2.6 GHz band would be based on WCDMA FDD and TDD technologies, similar to those being deployed in the 2.1 GHz (i.e. 3G) spectrum in Europe. Since this time, greater flexibility in spectrum use has resulted in likely market demand for unpaired spectrum for other TDD systems in the 2.6 GHz band (e.g. for WiMAX systems) as well as paired spectrum for WCDMA.

In the absence of a detailed study into WiMAX-UMTS coordination in border areas, European regulators are proposing to adopt the more stringent of the two field strength trigger values specified in ECC Recommendation 01-01, i.e. 21 dBμV/m/5MHz applying at, and beyond, the border for coordination between WiMAX systems (e.g. TDD-TDD) and between WiMAX and UMTS.

As discussed in the introduction to this report, the WiMAX Forum has commissioned this study to consider what constraints the 21 dBμV/m/5MHz coordination threshold places upon the rollout of WiMAX systems in border areas and, if appropriate, to propose a higher (i.e. less stringent) field strength threshold that might provide a more equitable balance between enabling the rollout of networks in border areas, whilst also protecting the rights of wireless operators in the neighbouring country who might be licensed to use the same frequency block.

[5] The coordination threshold is specified at 0km from the country border, i.e. at and beyond the international border.

3.4 Setting Field Strength Limits for Effective Border Coordination

A key issue for the study is to consider the appropriate field strength level for coordination of WiMAX and UMTS networks (i.e. the maximum field strength permitted from a network in one country without triggering coordination with the neighbouring operator), as well as the potential interference mitigation techniques that might assist in achieving coordination to the benefit of both operators. For scenarios where different technologies are used on either side of the border, mitigation techniques applicable to 'same' technology scenarios (e.g. the proposed 'preferential codes' in WCDMA) may not all be applicable, and need to be re-assessed.

To illustrate the challenge of coordinating different technologies, we first consider coordination of two single frequency networks both utilising the same technology and the same multiplexing method at a border. This is illustrated in Figure 3.1 below.

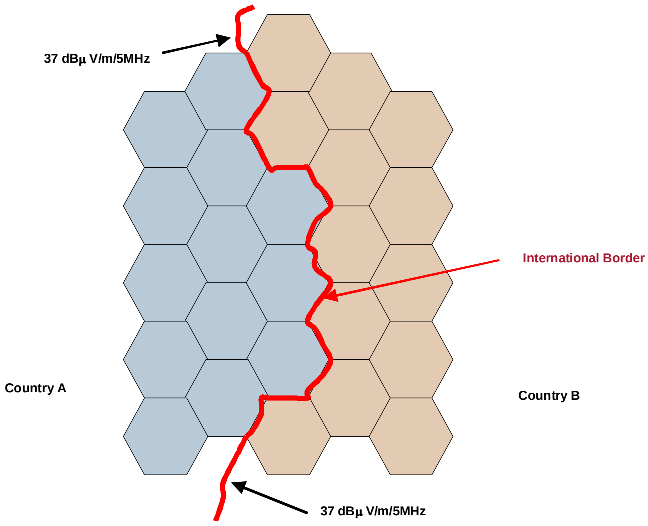

Figure 3.1: *Two coordinated single frequency networks using the same frequency, same technology, preferential codes and/or synchronisation [Source: Analysys Mason]*

This scenario can represent UMTS-UMTS (WCDMA-WCDMA) or WiMAX-WiMAX (OFDMA-OFDMA) systems. The ECC recommendation proposes that, for WCDMA, the use of preferential codes for cells in border areas means the two systems can co-exist without interfering with each other. Hence, a less stringent field strength trigger value is considered to be appropriate.

In the second scenario, shown in Figure 3.2, we consider two networks that use the same frequency, but different technologies (e.g. UMTS-WiMAX), and therefore cannot coordinate scrambling/spreading codes or logical channels. It should be noted that preferential frequencies cannot be used (as is the case with GSM and UMTS) because OFDMA uses wideband channels of up to 20 MHz, and there is insufficient spectrum to partition it in this way. Here we illustrate the interference from both networks falling to 21dBµV/m /5MHz at the international border, thereby complying with the ECC Recommendation 01-01 trigger level. There is an area between the two networks either side of the international border where coordination is necessary. This is shown as the area between the two green lines in Figure 3.2 below. It should be stressed that with mitigation of interference, achieved by coordination between the two network operators and depending on the technology being used (e.g. WiMAX to WiMAX or HSPA to HSPA) it is perfectly feasible to provide coverage within this area. For an HSPA to WiMAX coordination scenario, for example, it is possible that the coverage area can be increased by using mitigation techniques, but it is quite difficult to achieve 100% coverage. The objective of the international coordination threshold is therefore to strike a balance between minimising interference whilst not generating unnecessary delay and administrative overhead by forcing too many sites through a coordination process.

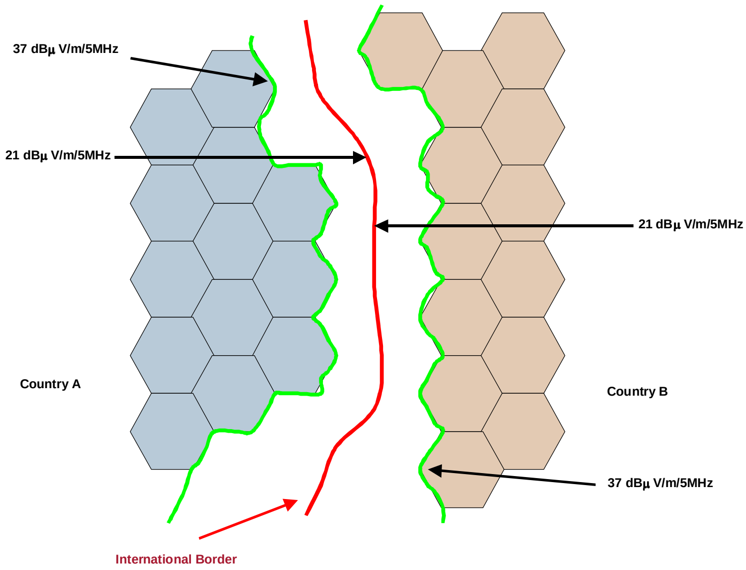

Figure 3.2: Two coordinated single frequencies using same frequency, but different technologies, and multiplexing with interference limit at international border [Source: Analysys Mason]

Of particular interest to this study is that, if the 21dBµV/m/5MHz level of acceptable interference can be increased, coordination is simplified and coverage areas (and network throughput) will be increased for operators on both sides of the border, i.e. the desired outcome of border coordination.

By way of illustration, Figure 3.3 below shows one approach to coordination, simply agreeing a new interference contour by negotiation with the two network operators. Normally, the negotiation between the network operators in neighbouring countries is co-ordinated through the respective regulators. This is consistent with ECC Recommendation 01-01, which states that coordination in border areas shall be based on bilateral or multilateral agreements ‘between administrations’.

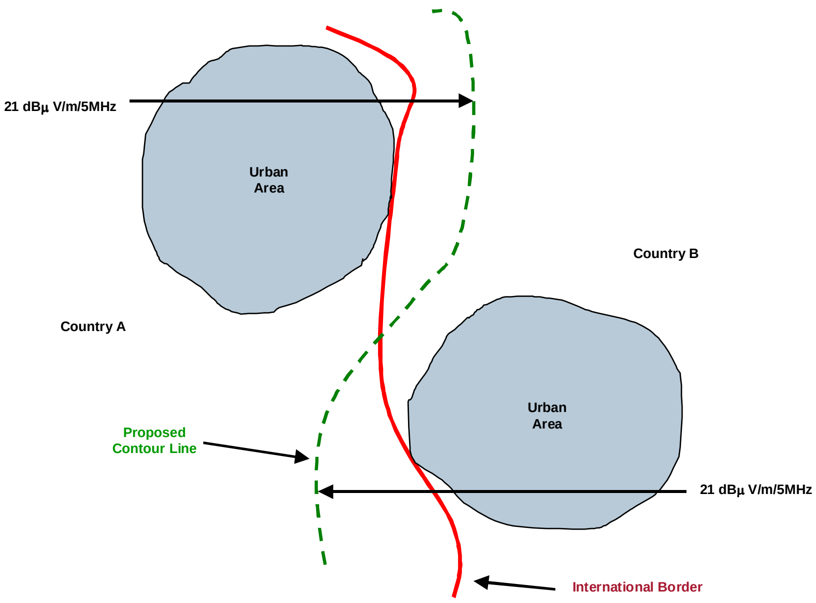

Figure 3.3: Two coordinated single frequencies using same frequency, but different technologies, and multiplexing with a contour line [Source: Analysys Mason]

4 Approach to Study

We commence our summary of our approach to the study with discussion on the choice of propagation model, in view of its relevance to the remainder of this section.

ECC Recommendation (01) 01 refers to two propagation models: ITU-R P.1546 and ITU-R P.452. Whilst the original analysis conducted for this study used these propagation models, we found that the implementation of these models in the cross border scenarios being proposed was not ideal in practice, and therefore we have used ITU-R P1812 for all modelling for the following reasons:

- ITU-R P1546 is limited to the case where the transmitter is above the height of local clutter[6]. In mobile broadband networks the transmitter (mobile or base) is not always above the height of local clutter, especially in urban areas. ITU-R P1812 is valid for transmitter heights between 1m and 3000m[7]. For this reason, we have used the later ITU-R P1812, rather than ITU-R P1546 that is suggested in ECC Recommendation (01) 01 for general site modelling, which we consider in phase one.
- For path specific propagation for point-to-areas paths in the VHF and UHF bands (30MHz to 3GHz) the ITU now (since 2007) recommends that ITU-R P1812[8] be used, rather than ITU-R P 452, which remains in force for point-to-point microwave links. For this reason we have used ITU-R P1812, rather than ITU-R P452 that is suggested in ECC Recommendation (01) 01 for site specific modelling, which we consider in phase two.

The most recent ATDI ICS Telecom implementation of P.1812, updated for this study, has been used throughout our analysis. ATDI's implementation of the P.1812 model has validated against a second independent implementation of P.1812 developed by BT.

Our approach to the study was to break the analysis into two distinct phases of interference modelling, as described below.

► *Phase one modelling*

The first phase of the study consisted of a single interferer-victim path using smooth earth curves in urban, suburban and rural environments. In this phase we consider a single interferer. The objective was to **review the trigger values proposed in ECC Recommendation (01) 01.** This phase included preparation of link budgets and required Carrier to Interference (C/I) ratios for each technology. Key link budget parameters were used, along with propagation prediction based on

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6 ITU-R P1546, annex 6, table 4

7 ITU-R P1812 annex 1, table 1

8 ITU-R P1812 The recommendation (page 2)

Recommendation ITU-R P.1812 to explore the impact of a range of **trigger values** on both the interfering and victim links.

The modelling in this phase was completed with Microsoft Excel.

► *Phase two modelling*

The second phase of the study consisted of several European cross-border scenarios and considered many (typically one million) interferer-victim paths, representative of deployment scenarios that might occur in practice in European border areas. This phase of modelling used the site specific propagation model Recommendation ITU-R P.1812.

In this phase of modelling, we considered the aggregated interference power of many interferers. The objective was to determine the **impact on network deployment in border areas.** This was explored in the form of a European case study, based upon the Basle and Maastricht border regions. Combinations of WiMAX Handheld, WiMAX Notebook and HSPA coverage were analysed.

The modelling in this phase was completed with ATDI ICS Telecom version 9.1.4 and a database.

These two phases of modelling are described in more detail in Sections 4.1 and 4.2 below.

4.1 Review of Trigger Values Proposed in ECC Recommendation (01) 01

The purpose of Phase 1 of the study was to investigate the impact of the proposed trigger level of **21dBμV/m/5MHz** from ECC Recommendation (01) 01 on the deployment of WiMAX systems in the 2.6GHz band, and, if appropriate, to recommend suitable revision of the trigger value to a value applicable to WiMAX systems without causing undue burden on the coordination of those systems in border areas.

Our overall approach to Phase 1 of the study is summarised in Figure 4.1 below.

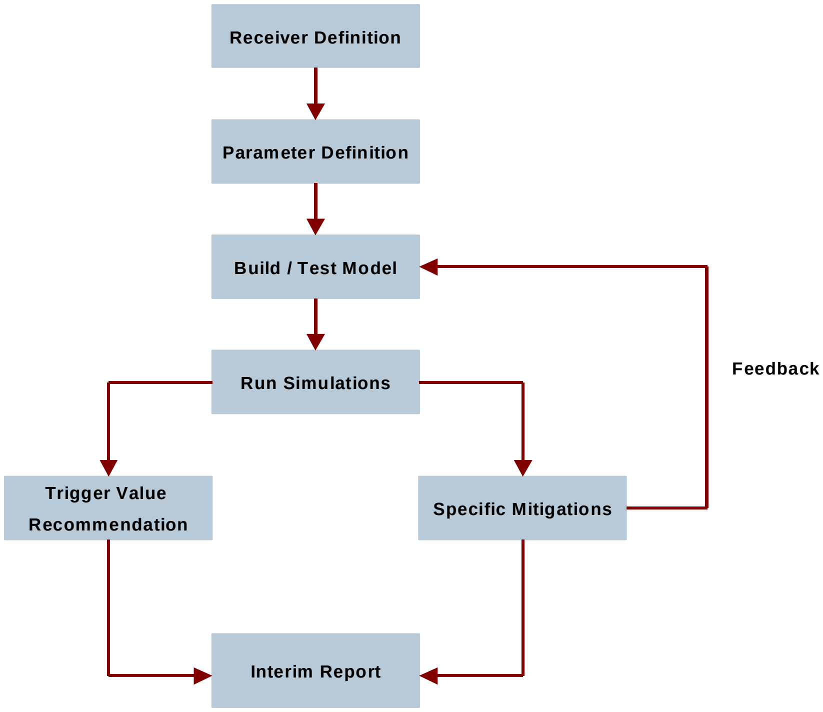


Figure 4.1: Phase One Methodology [Source: Analysys Mason]

A brief description of our approach to each task is further described below.

Receiver Definition

We have calculated UMTS and WiMAX receiver sensitivities based upon uplink and downlink link budget calculations for both technologies. The receiver sensitivity, combined with the interference margin and the noise power, defines the sensitivity of the receiver from interference from neighbouring networks, and we have used this parameter in our Excel model to consider the impact of interference at different levels on the receiver's ability to maintain data throughput.

Details of the link budgets developed for the study, and used within the modelling described in this report, are included in the Annexes of this report.

Parameter Definition

The WiMAX Forum asked us to develop link budgets for the study for approval by members of the WiMAX Forum study team prior to building these parameters in to our network and interference models.

We have therefore undertaken an assessment of WiMAX network planning assumptions for different cell type, quality of service and data throughput service targets.

We then developed link budgets, planning assumptions and propagation models for use in simulation of network performance for WiMAX, which have been discussed and agreed with the WiMAX Forum.

The following parameters have been agreed with the WiMAX Forum study team for the purposes of this study:

- Effective Isotropic Radiated Power (EIRP)
- Receiver Gains
- Base station and User equipment losses
- Channel Size
- Interference Margin
- Propagation Model
- Fade Margin.

Parameters for UMTS networks assumed in the study are referenced to the 3GPP Release 7 Specifications (i.e. HSPA, pre 3G-LTE).

Building and Testing of Model

For Phase 1 of the study, to investigate the impact of the proposed trigger level of 21dBμV/m on the deployment of WiMAX systems, and to recommend suitable revision of the trigger value to a more applicable value, we have developed a model using Microsoft Excel, which calculates, using the trigger level proposed in the ECC Recommendation, the impact on network deployment (either EIRP or cell range) in border areas in order to avoid exceeding the stated threshold.

We have assumed that the most sensitive border coordination scenario will be interference from macro base stations of neighbouring networks, since the effect of the interfering field strength will be more pronounced at the base station due to its antenna gain and height.

Due to the way that European cross border prediction is normally conducted, field strength is typically predicted at 3m above ground level (consistent with the worst-case height of a mobile receiver), and so our model has assumed this receiver height for test points.

We have implemented Rec. ITU-R P.1812 smooth earth curves for urban, suburban and rural environments within the model for the calculation of signal propagation.

Simulations

We have carried out a series of simulations using the Excel model to assess the impact of the proposed ECC trigger level on network performance in the presence of interference, and how the impact changes if the stated threshold is relaxed.

We have modelled base station to base station interference in the following range of scenarios:

- A UMTS HSPA network interfering with a WiMAX network designed to provide hand held coverage
- A UMTS HSPA network interfering with a WiMAX network designed to provide coverage to laptop devices
- A WiMAX network designed to provide hand held coverage interfering with a UMTS HSPA network
- A WiMAX network designed to provide laptop coverage interfering with a UMTS HSPA network
- A WiMAX network designed to provide hand held coverage interfering with another WiMAX network designed to provide hand held (without TDD synchronisation)
- A WiMAX network designed to provide laptop coverage interfering with another WiMAX network designed to hand held coverage (without TDD synchronisation)
- A WiMAX network designed to provide hand held coverage interfering with a WiMAX network designed to provide laptop coverage (without TDD synchronisation)
- A WiMAX network designed to provide laptop coverage interfering with a WiMAX network designed to provide laptop coverage (without TDD synchronisation).

These are repeated for the different morphologies; urban, suburban and rural. In the case of urban environment, the base station EIRP and cell size is selected for in-building coverage, while in the case of suburban and rural, the budget will be for outdoor coverage only.

Since both WiMAX and UMTS HSPA systems respond to interference by employing rate adaption, but at the expense of data rate, we have generated results comparing interference (coordination threshold) against data rate.

Simulations of these scenarios have been used to generate graphs of trigger level versus impact on data throughput, and also the necessary separation (in km) between base stations of systems in border areas to achieve different stated threshold limits.

The critical cases are identified from the analysis and the coordination threshold that gives the most equitable balance of impact to victim and interferer is derived.

Trigger Value Recommendation

We used the results of the simulations in Phase 1 of the study to assess the most appropriate level of field strength trigger offering protection of TDD and FDD systems in border areas, whilst ensuring that sites can be rolled out to provide the necessary coverage in those areas.

We have considered two main factors within our analysis:

- The impact on the **interfering** cell of a change in coordination threshold, in terms of its ability to provide service in the border area
- The impact on the **victim** cell of a change in coordination threshold, in terms of its ability to serve subscribers in the presence of incoming co-channel interference.

► *Impact on the interfering cell*

The assessment considered the impact on the interfering cell in terms of:

- the minimum separation distance between cell edge and the international border
- the downlink data throughput (bps/Hz) for a mobile on the international boundary.

The steps for this process are described below:

Step 1: Link budgets for HSPA and two alternative WiMAX deployments, providing reception to Hand Held and Notebook mobile stations respectively, were constructed. These are shown in Annex A and B of this report. From these budgets the following parameters, derived from the link budgets, are used in our border coordination model: Base station EIRP and base station C/I.

The C/I calculations were repeated for a range of modulation schemes, and the results are shown in the Figure below. The throughput shown is for a BLER of 10%.

WiMAX BS C/I	*WiMAX UE C/I*	*HSPA BS C/I*	*HSPA UE C/I*	*Throughput (bps/Hz)*	*Modulation*
5.72	11.03	-15.88	-13.82	0.9	QPSK 1/2
8.62	13.93	-12.78	-10.72	1.35	QPSK 3/4
11.02	16.33	-10.28	-8.22	1.8	16 QAM 1/2
14.52	19.83	-6.28	-4.22	2.7	16 QAM 3/4
18.34	23.65	N/A	N/A	3.6	64 QAM 2/3
19.82	25.13	N/A	N/A	4.05	64 QAM 3/4

Figure 4.2: Minimum C/I values required for selected modulation and data throughputs

C and I were calculated as follows:

- C is the minimum power required by the receiver for the given modulation, taking into account N (noise power), the channel bandwidth and the required SNIR for the modulation scheme
- I (interference power) is derived from the interference margin included in the link budgets. Interference margin equals (N+I)/N. Thus the amount of continuous interference a link can tolerate is determined solely by the interference margin included within its design.

Step 2: The cell size of the interfering base station was calculated using the appropriate link budget depending on the technology being used. We determined the cell size by using the lowest data rate available and the slow fade margin required to satisfy fading at 75% of locations on the cell edge. This is equivalent to 90% locations across the whole area of the cell assuming: [9] [10]

- a standard deviation for location variability of 8dB
- propagation losses with decay law of 3.52.

The cell radius for indoor coverage was used when considering urban environments, outdoor when considering suburban and rural environments. The Figure below summarises all cell radii used throughout the study:

Enviroment	*UMTS HSPA (km)*	*WiMax Handheld*	*WiMax Notebook*
Urban (Indoor)	1.21	0.49	0.63
Suburban (Outdoor)	6.68	2.69	3.49
Rural (Outdoor)	27.03	12.71	16.51

Figure 4.3: Cell Radii from link budgets in Annex A & B [Source: Analysys Mason]

Steps 1 and 2 are illustrated in Figure 4.4.

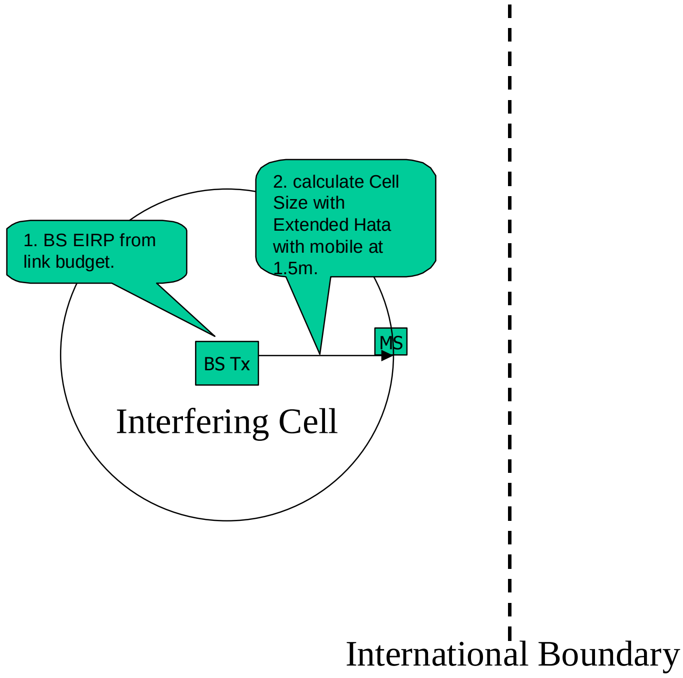


Figure 4.4: Calculating cell size of interfering Base Station [Source: Analysys Mason]

[9] Microwave Mobile Communications, William C. Jakes 1974 p127

[10] COST 231 and Extended Hata propagation models have a decay law of 3.52 for BS heights of 30m (or less), and distances of 20km or less in Urban, Suburban and Rural environments.

Step 3: Interference is predicted from a base station at the border, with propagation prediction based on Rec. ITU-R P.1812, assuming 50% locations and 10% time, at a 3m test point, as shown in Figure 4.5.

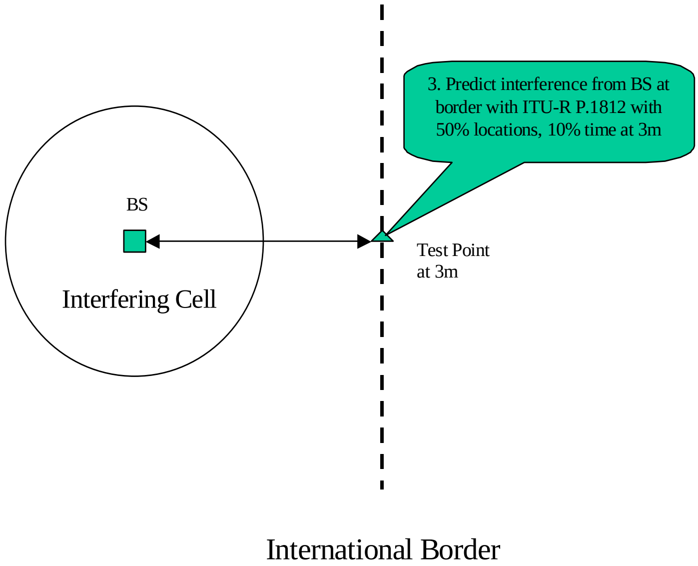


Figure 4.5: Predicting interference using ITU-R P.1812 from BS to Test Point at 3m [Source: Analysys Mason]

Step 4: The minimum distance between the interfering base station and border is calculated to achieve compliance with a range of thresholds from 0 to 100 dBμV/m. A graph of coordination threshold against minimum separation distance is plotted.

Step 5: The throughput of a mobile station at 1.5m on the border was also calculated depending on the signal to interference and noise ratio (SINR) and modulation schemes. A graph of throughput against coordination threshold was plotted from this.

Steps 4 and 5 are illustrated in Figure 4.6.

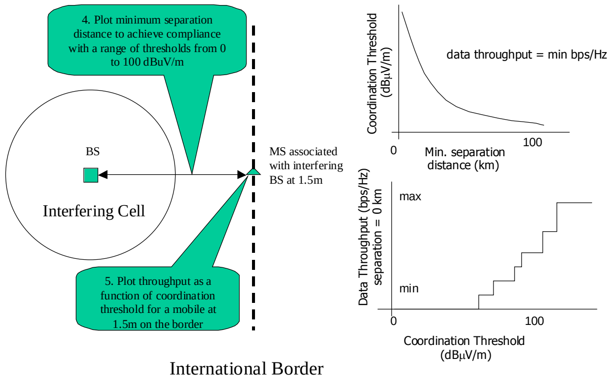


Figure 4.6: Calculating minimum distance between base station and border, and throughput at border for a mobile station [Source: Analysys Mason]

► *Impact on the victim cell*

We then assessed the impact on the victim cell of a change in coordination threshold, for a range of thresholds. This assessed the impact on data throughput. As the base station is the most significant victim (i.e. a base station is more sensitive to interference than a mobile), we have assumed that it is the uplink data throughput (victim base station receive) that will be most severely impacted by an increase in field strength from the interfering cell.

Whilst the coordination limit strictly applies to the international boundary, we have noted that it is unreasonable to assume that the victim base station will be both: (i) located on the international boundary and (ii) have antenna(s) facing the source of interference (i.e. away from the country where coverage is required.) Thus, we have placed the victim cell in our model such that the international boundary coincides with cell edge and a propagation loss applied to the interference as appropriate for a typical interfering cell that complies with the given coordination threshold. The cell size was determined for 75%/90% cell edge/area probability, as described above.

The steps for assessing impact on the victim cell process were carried out as follows:

Step 1: An interfering base station is placed at a distance equal to its cell radius away from the international border.

Step 2: The coordination threshold was varied at the 3m test point on the border, and the interfering base station EIRP was varied to comply with each value of coordination threshold considered.

Step 3: The interference was predicted at the **victim base station** using Rec. ITU-R P.1812, predicted for 50% locations and 10% time.

Step 4: The throughput of the victim base station was calculated based on the C/I achieved for the minimum carrier power (C) allowed for in the link budget, and is plotted as a function of coordination threshold, as shown in Figure 4.7.

It should be noted that the cell dimension is based on an interference margin of 3 - 5dB and the minimum data throughput, as illustrated in the appropriate link budget. Thus, when interference is less than that allowed for by the interference margin, data throughput increases above the minimum level.

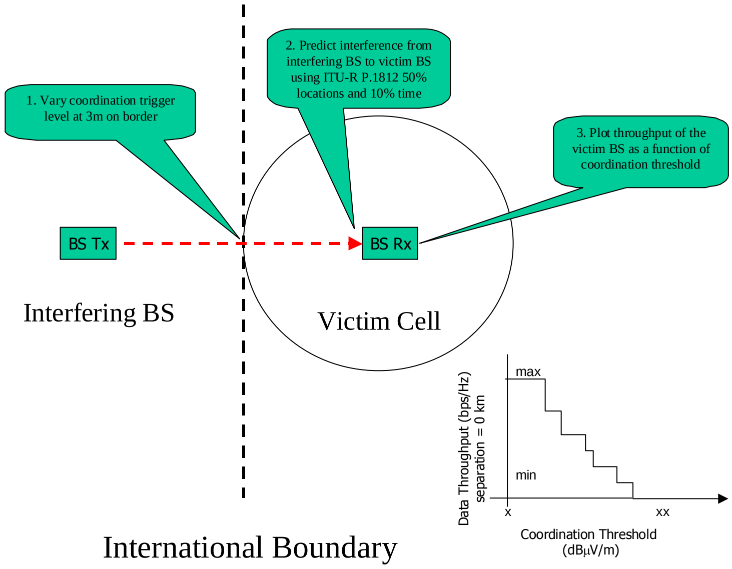


Figure 4.7: Impact of Coordination Threshold on Throughput of Victim Base Station [Source: Analysys Mason]

4.2 Impact on Network Deployment in Border Areas – European Case Study

Using the revised trigger values determined from Phase 1 of the study as our basis for analysis, the second phase of modelling consisted of assessing the impact of these trigger values in several European cross-border scenarios. In considering typical network deployments, we therefore considered many (typically one million) interferer-victim paths, typical of real network deployment. Propagation prediction was undertaken using the site specific model Recommendation ITU-R P.1812.

In this phase we consider the aggregated interference power of many interferers. The objective was to determine the **impact on network deployment in border areas.** The modelling in this phase was completed with ATDI ICS Telecom version 9.1.4 and a database of derived site locations.

Basle and Maastricht border regions were chosen for this phase of modelling, and combinations of WiMAX Handheld, WiMAX Notebook and HSPA coverage were analysed. Basle and Maastricht were selected because they represent a good mixture of geo-types (i.e. representing a combination of urban, suburban and rural areas). Both regions have urban areas on either side of the border, thus presenting the most challenging cross border coordination situation.

The Basle scenario is summarised in Figure 4.8 to Figure 4.10 below:

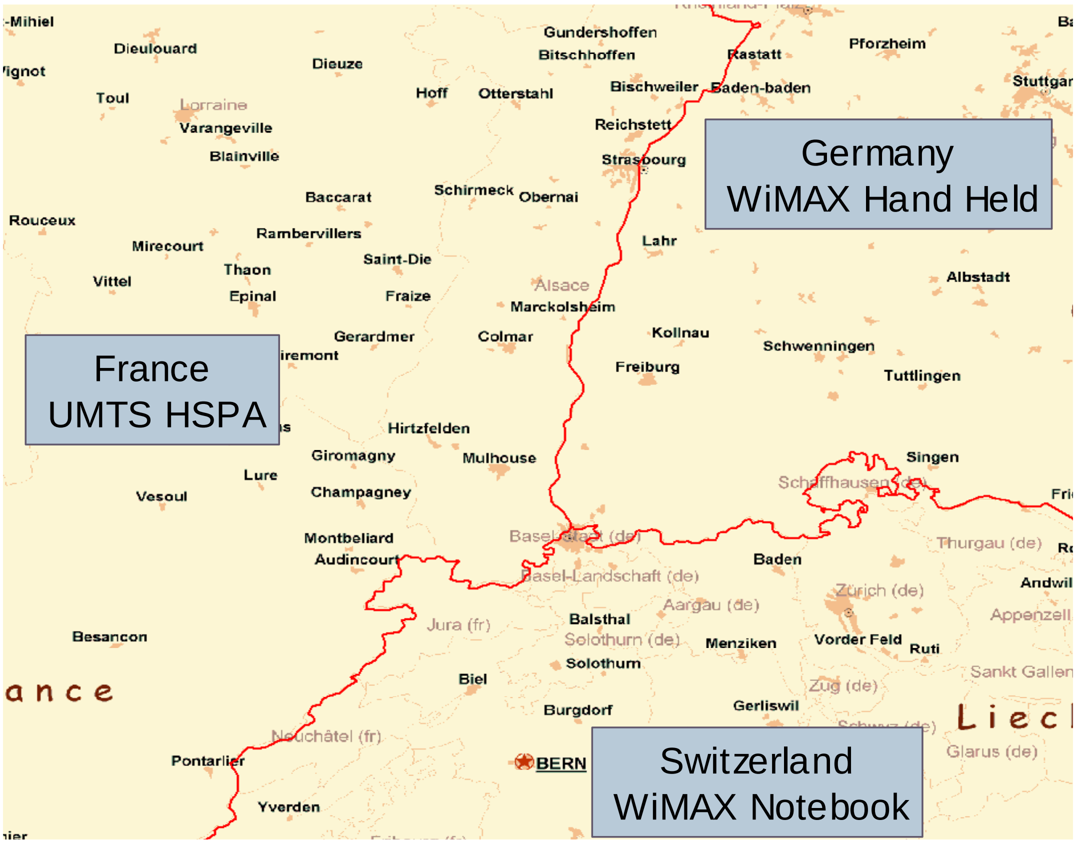


Figure 4.8: Basel Scenario Map [Source: Analysys Mason]

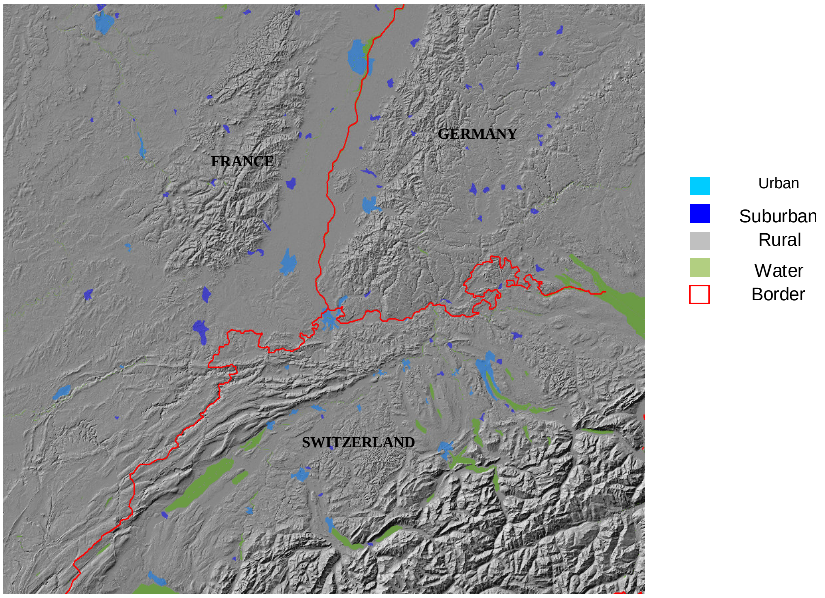


Figure 4.9: *Basle Border Environment [Source: Analysys Mason]*

The following figure shows three uncoordinated reference networks that we developed for the study to assess this border area. In the diagram, urban sites are shown in green, suburban in red, and rural in blue.

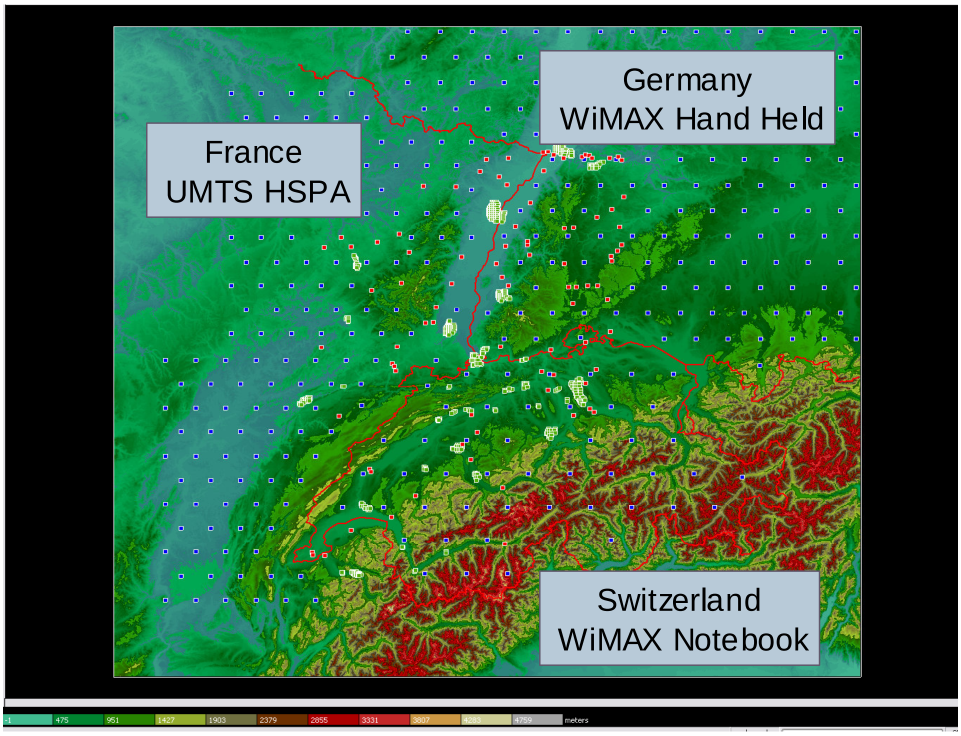


Figure 4.10: *Basel Scenario DTM [Source: Analysys Mason]*

Figure 4.11summarises the Maastricht scenario.

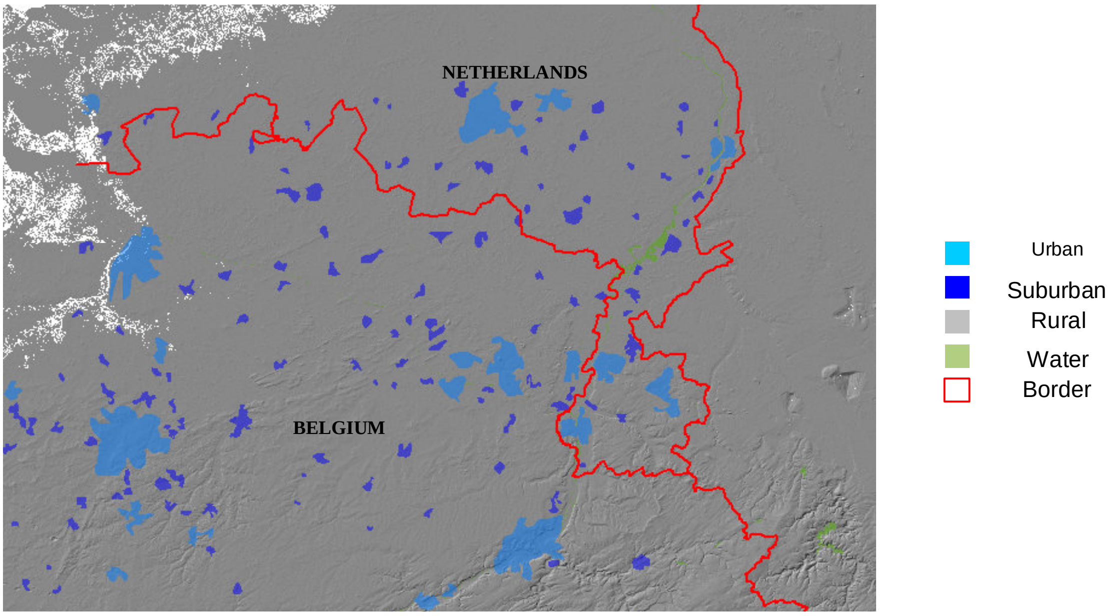


Figure 4.11: Maastricht Border Regions [Source: Analysys Mason]

4.2.1 An overview of the phase two modelling steps

An overview of the approach taken for Phase 2 is as follows:

1. We obtained a 50m resolution digital terrain map from SRTM data for the selected border regions.

2. We then designed reference networks in each country based on the technology being used (i.e. WiMAX and HSPA). These were designed using the link budget parameters summarised in Annex A and Annex B of this report.

3. We then verified reference network coverage from each of the networks to ensure that our modelling was representative of likely coverage strategies that operators might deploy in these areas in practice.

4. We created test points at 3m along the international border, in order to predict the field strength at each of these test points, in accordance with ECC recommendation (01)01.

5. We modelled the signal propagation from base stations to these test points.

6. We then removed the most significant interfering site from any group of sites that collectively breached the coordination threshold at any test point.

7. Once the reference networks had been reduce to a set of sites that complied with the regulatory trigger threshold, we then performed an interference analysis between interfering base stations and victim base stations to confirm that the calculated C/I for each technology was not breached.

8. Some interference mitigation techniques were used, and the scenario was simulated with each technique applied. Graphs of percentage of sites requiring coordination against aggregated trigger level and aggregated interference against Cumulative Density Function of victim base stations were plotted.

9. We then repeated the whole process for the remaining scenarios.

The following scenarios were modelled:

- WiMAX Handheld (Germany) – WiMAX Notebook (Switzerland)
- WiMAX Handheld (Germany) – HSPA (France)
- WiMAX Notebook (Switzerland) – HSPA (France)
- WiMAX Notebook (Switzerland) – WiMAX Handheld (Germany)
- HSPA (France) – WiMAX Notebook (Switzerland)
- HSPA (France) – WiMAX Handheld (Germany).

4.2.2 Detailed description of each step in the process

► *Step 1: Obtain 50m resolution digital terrain map.*

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate a high-resolution digital topographic database of Earth. SRTM consists of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

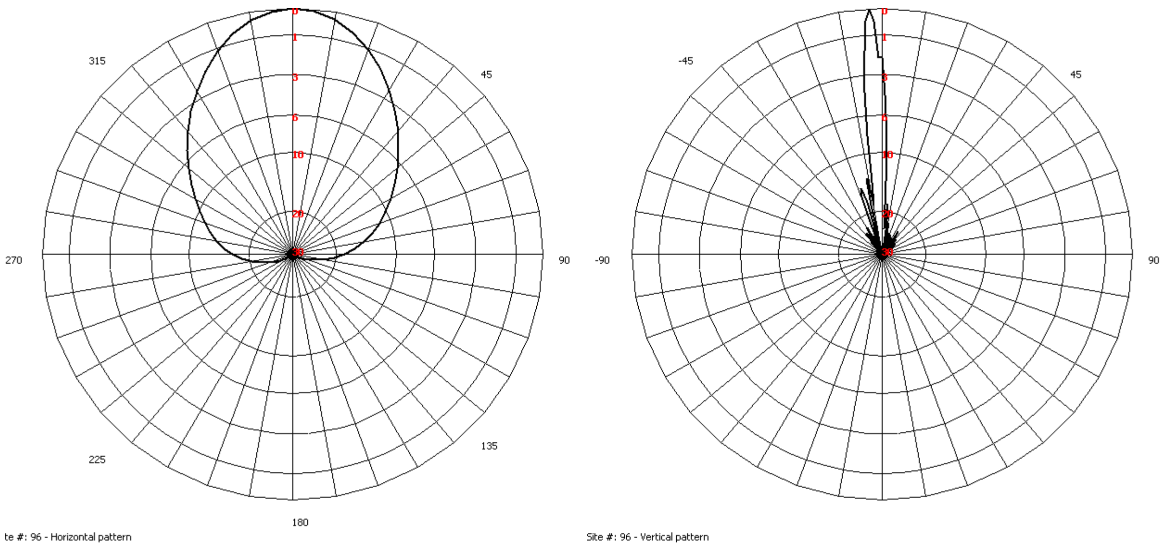
NASA has released version 2 of the Shuttle Radar Topography Mission digital topographic data (also known as the ‘finished version’). Version 2 is the result of a substantial editing effort by the National Geospatial Intelligence Agency, and exhibits well-defined water bodies and coastlines and the absence of spikes and wells (single pixel errors).

The SRTM data was projected into an appropriate UTM zone (31 for Maastricht and 32 for Basel) to create a grid of 50m square pixels as required by the radio planning tool.

► *Step 2: Design the reference network*

ATDI ICS Telecom v9.1.4 was used to build reference mobile networks in each country for the selected technology (HSPA, WiMAX Handheld and WiMAX Notebook). Tri-sector sites were deployed at the appropriate cell density in urban, suburban and rural areas. The reference networks were constricted in line with the cell radii shown in Section 4.1 of the report, and the link budgets in Annex A and Annex B.

Three 65 degree tri-sector antennas with a two degree down tilt were assumed at each base station. The selected antenna pattern is shown in the polar plots below. A down tilt of two degrees was applied. Note that the secondary lobes on the upper half of the elevation pattern are suppressed to reduce transmitted and received interference.



Note: 0 degrees on the horizontal pattern is the antenna azimuth; 0 degrees on the vertical pattern is the horizon.

Figure 4.12: *Horizontal and vertical antenna patterns for a typical 65 degree antenna*

► *Step 3: Verify reference network coverage*

Coverage for each reference network was verified using ITU-R P.1546, using 50% variability and 50% time assumptions, along with the planning level from the relevant link budget. The example below shows coverage in an urban area. At this stage any unnecessary sectors were removed from the reference networks.

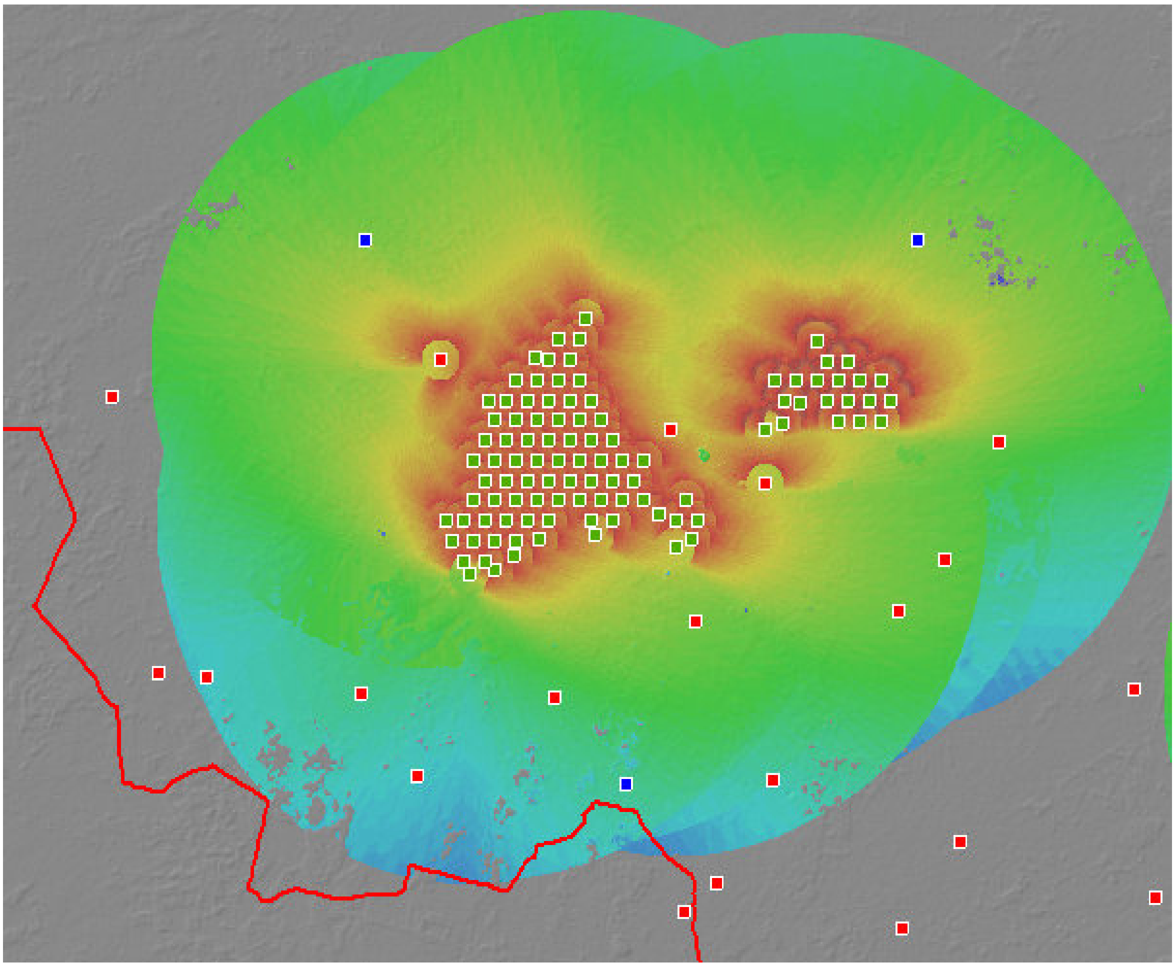


Figure 4.13: *Coverage Planning [Source: Analysys Mason]*

► *Step 4: Create test points at 3m along the international border.*

A section of the relevant international border was imported into the ATDI ICS Telecom tool, and test points were generated at 1km intervals along this line.

Figure 4.14 shows the test points generated along the Netherlands and Belgium border in the Maastricht area.

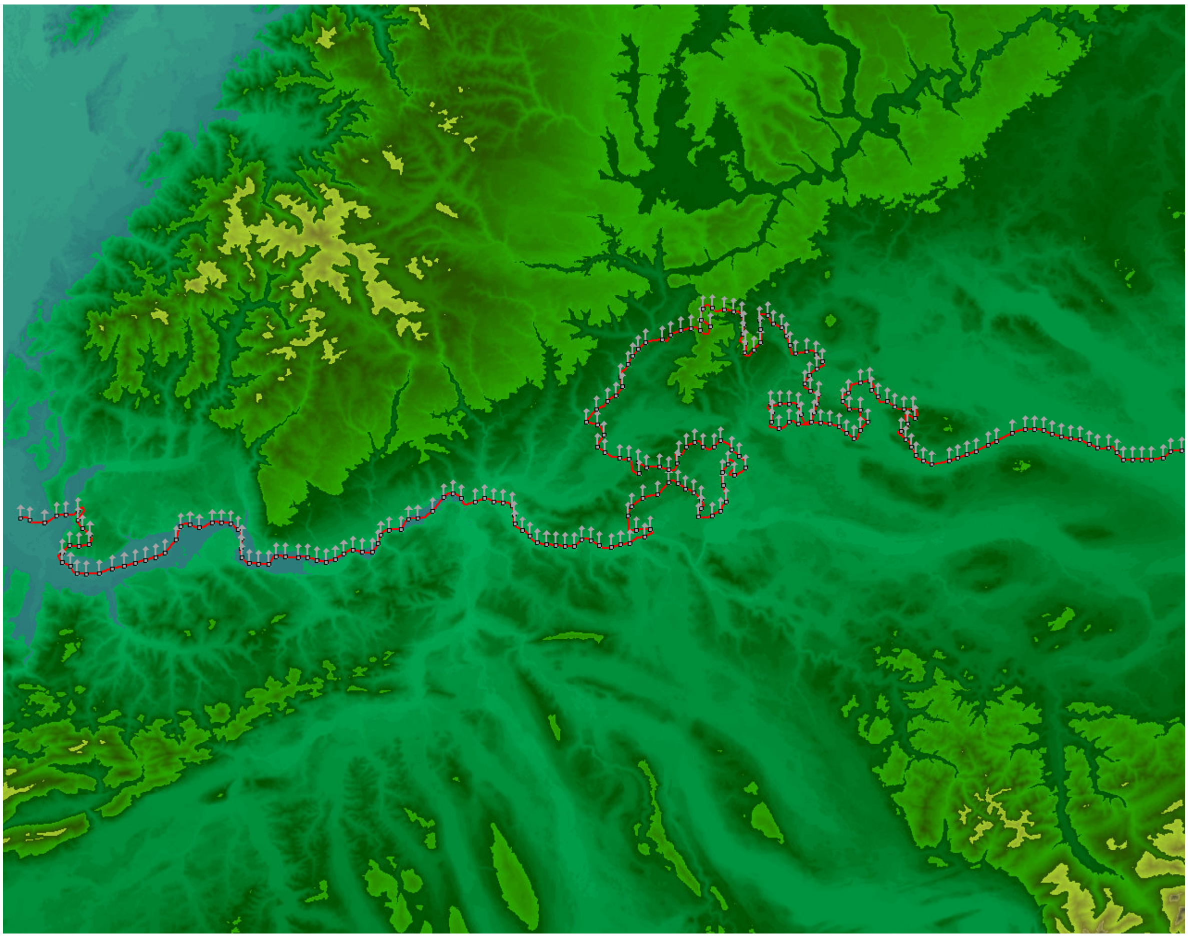


Figure 4.14: Netherlands and Belgium test points [Source: Analysys Mason]

► *Step 5: Perform interference analysis from base stations to test points.*

ICS Telecom was then used to perform radio interference modelling. The propagation model was Recommendation ITU-R P.1812, with 50% locations and 10% time was used to predict interference.

Figure 4.15 shows the configuration of the propagation model.

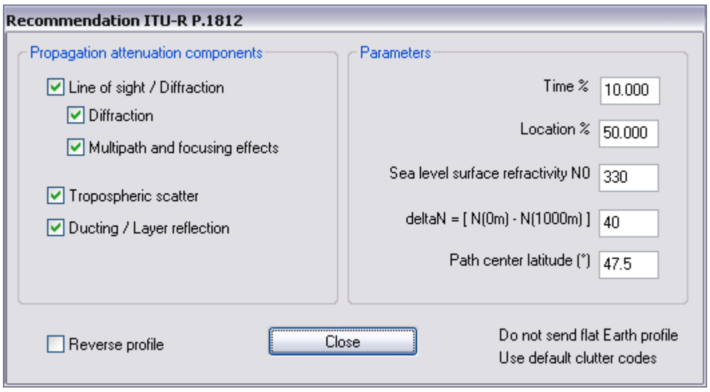


Figure 4.15: ITU-R P. 1812 ATDI ICS Telecom parameters [Source: Analysys Mason]

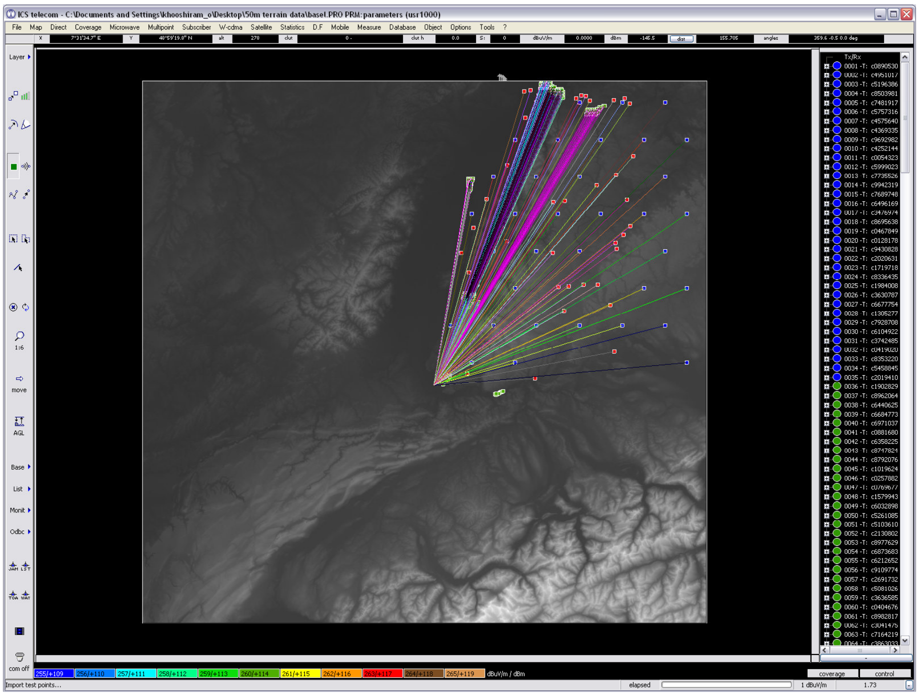


Figure 4.16: ICS Telecom calculating Field Strengths at a test point. [Source: Analysys Mason]

The field strength for every base station to test point combination was exported to an SQL database.

► *Step 6 Remove the most significant site from any group of sites that collectively breach the coordination threshold at any test point.*

Co-channel interference was calculated at each test point using the **Bonn Summation** power sum and comparison was made with the coordination threshold determined in Phase 1 of the study. If the threshold was breached then the most significant interferer was removed from the reference network and the summation was repeated. This is repeated for each test point. This task was achieved using an automated script and the database of field strength for every base station to test point combinations.

For Bonn Summation, the power sum is obtained as follows:

- starting with the highest interfering source, the power values equivalent to the interfering field strengths are added, one after the other;
- at each summation, the result is compared to the previous one;
- if the increase in power is greater than or equal to 0.5 dB, the summation process continues and the next interfering transmitter is taken into account as well;
- if the increase in power would have been less than 0.5 dB, the summation process is stopped and 0.5 dB is added instead, giving the result of the power sum.
- The final 0.5 dB is used to represent the entire remaining interfering transmitter, which each contribute less than 0.5 dB.

At the end of this step, the sum of interference from the remaining cells in the reference network should comply with the threshold value at every test point.

► *Step 7: Confirm that C/I is not breached.*

As a final cross check, we undertook interference analysis between interfering base stations and victim base stations to confirm that the calculated C/I is not exceeded.

Figure 4.17 illustrates BS to BS interference being calculated.

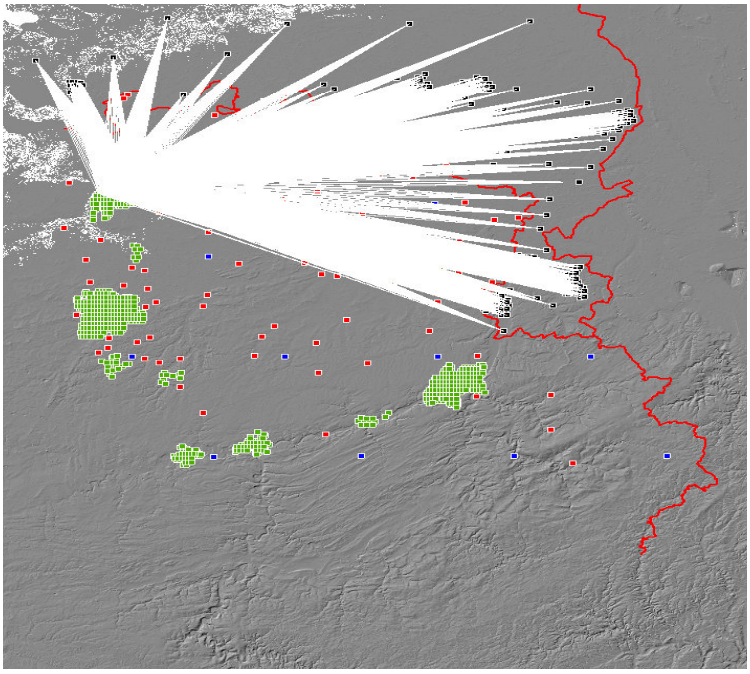


Figure 4.17: Calculating BS to BS Interference [Source: Analysys Mason]

- Step 8: Use 6-degree down tilt and 3dB reduction in power as interference mitigation techniques for all scenarios simulated. Produce charts of aggregated trigger level against percentage of victim base stations and percentage of interfering base stations that has to go through coordination against aggregated trigger level.

► *Step 9: Repeat the whole process for the remaining scenarios.*

The whole process was then repeated for each scenario being modelled.

4.2.3 Modelling Assumptions

The modelling assumptions in Phase 2 of the study were:

- Parameters as per link budgets developed in Phase 1 of the study and provided in Annex A and Annex B
- Reference networks were designed in order to provide indoor coverage in urban areas and outdoor coverage in suburban and rural areas.
- The propagation model ITU-R P.1812 with 50% locations and 10% time was used to predict the amount of interference being generated to the victim base stations.

5 Applicability of ECC (01)01 Trigger Values to Mixed Technology Scenarios

The following section describes the results obtained from the analysis conducted during Phase 1 of this study.

As described within our approach to the study, we have considered two main factors within this phase of the analysis:

- The impact of the coordinating threshold on the interfering cell, in terms of its ability to provide service in the border area

- The impact on the victim cell of a change in coordination threshold, in terms of its ability to serve subscribers in the presence of incoming co-channel interference.

Results presented in this section are therefore divided into two sections:

- Distance from interfering BS to international border versus trigger level
- Impact of trigger level on data throughput at victim and interferer.

5.1 Distance from interfering BS to international border versus trigger level

This section details the minimum distance between a given base station and the international border necessary to avoid breaching a given coordination trigger threshold. Raising the threshold reduces the number of base stations that need to go through the time-consuming coordination process. However, if the trigger is too high then victim systems will suffer an unacceptable drop in performance. Our rationale has therefore been to determine appropriate trigger thresholds that balance the need to protect victim systems whilst avoiding an unnecessary number of regulatory coordination requests for individual transmitting base stations to be coordinated.

We have used the base station heights and EIRP for HSPA and WiMAX as detailed in Appendix A and Appendix B of this report, in conjunction with the propagation model ITU-R Rec.P1812. The coordination trigger level is measured at 3m above ground.

We have noted that there is a significant reduction in interference measured at 3m compared to that measured at a typical base station height. This observation is particularly relevant to TDD-TDD and mixed technology (TDD-FDD) border scenarios that might arise as a result of flexible use of the 2.6 GHz band, since in those cases, base-base coordination scenarios will arise in addition to the base-mobile scenario which is the normal scenario in the case of FDD-FDD coordination. For base-to-base coordination, it appears that measurement of interference at the base station height (e.g. 30 metres for rural areas) will be more relevant.

ITU-R Rec.P1812 parameters assumed in our analysis are 10% of time and 50% of locations.

We have repeated the calculation of the distance required between a given base station and the border for each type of interferer being considered with the study, and in each environment (urban, suburban, and rural.)

The different interferer scenarios assessed were as follows:

- A UMTS HSPA network interfering with a WiMAX network designed to provide hand held coverage
- A UMTS HSPA network interfering with a WiMAX network designed to provide coverage to laptop devices
- A WiMAX network designed to provide hand held coverage interfering with a UMTS HSPA network
- A WiMAX network designed to provide laptop coverage interfering with a UMTS HSPA network
- A WiMAX network designed to provide hand held coverage interfering with another WiMAX network designed to provide hand held (without TDD synchronisation)
- A WiMAX network designed to provide laptop coverage interfering with another WiMAX network designed to hand held coverage (without TDD synchronisation)
- A WiMAX network designed to provide hand held coverage interfering with a WiMAX network designed to provide laptop coverage (without TDD synchronisation)
- A WiMAX network designed to provide laptop coverage interfering with a WiMAX network designed to provide laptop coverage (without TDD synchronisation).

The results illustrate that, in an urban environment, both reduced antenna height and a more challenging propagation environment result in lower interference for a given distance. Conversely, in the rural environment, the combination of open space and taller cell sites give higher levels of interference at a given distance.

We have observed that Rec. ITU-R P.1812 field strengths fall significantly in response to a fall in receiver height below 10m. For example, consider a link in an urban environment, with a transmitter at 15m and a receiver 500m away at 15m. Changing the receiver from 15m (the height of an urban BS) to 3m (the height of the test point) results in a fall in field strength of 39dB. This is partially offset by the additional distance a typical victim base station will be from the test point, which is on the boarder. Even so, a 15m base station 500m from the border will receive significantly higher levels of interference than that predicted at a 3m test point on the border; according to ITU1812; 25dB higher in this example (urban environment). See Figure 5.1 below. For this reason, the trigger threshold will need to be significantly lower than the level of interference that a base station can tolerate.

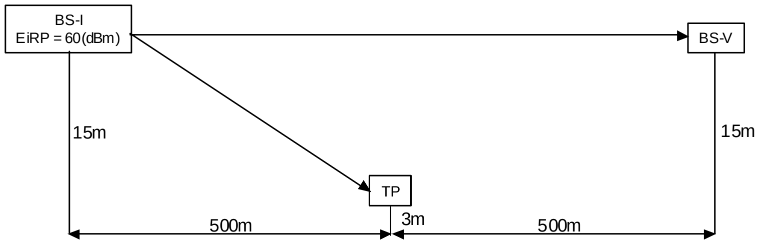


Figure 5.1: Illustration of paths from Interferer to test point and base station

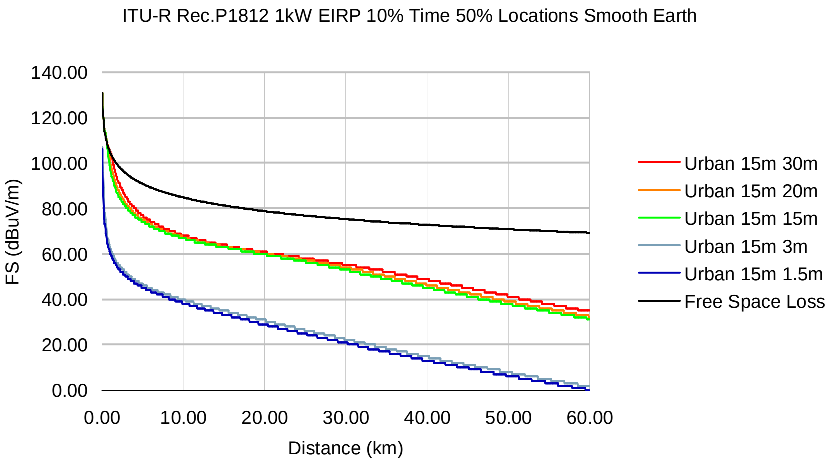


Figure 5.2: Comparison Field Strength predicted with ITU-R P.1812 and Free Space for 1kW EIRP for a range of Rx heights - Urban

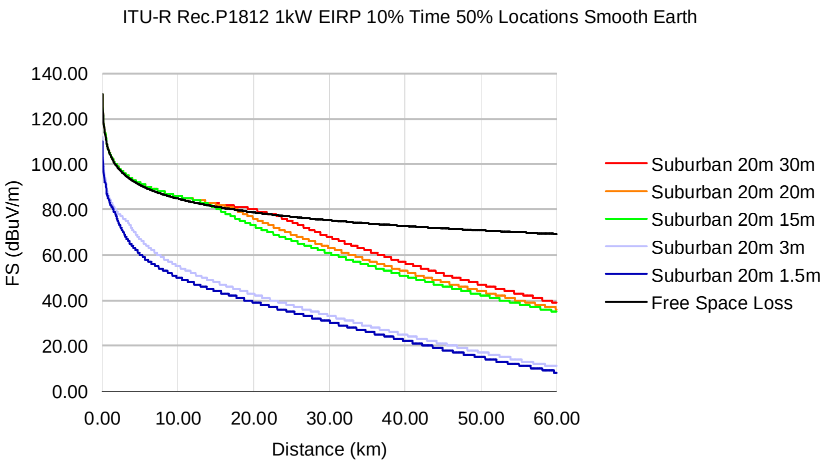


Figure 5.3: Comparison Field Strength predicted with ITU-R P.1812 and Free Space for 1kW EIRP for a range of Rx heights - suburban

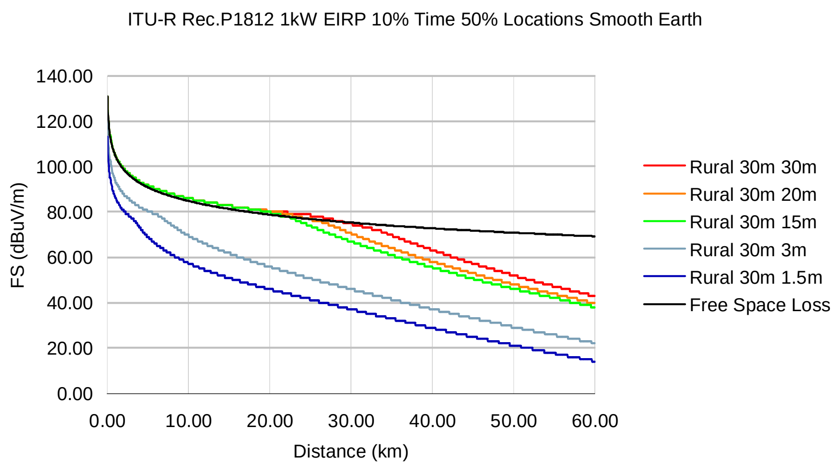


Figure 5.4: Comparison Field Strength predicted with ITU-R P.1812 and Free Space for 1kW EIRP for a range of Rx heights - Rural

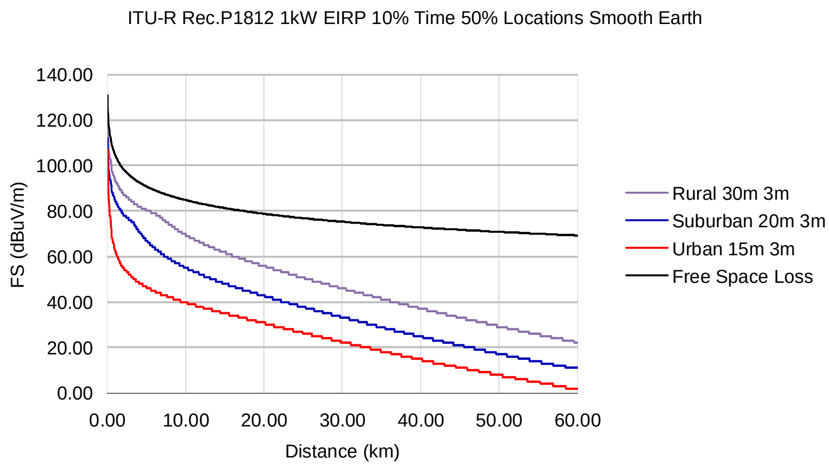


Figure 5.5: Comparison Field Strength predicted with ITU-R P.1812 and Free Space for 1kW for a range of environments – Rx 3m

The following charts (Figure 5.6 to Figure 5.11) show the minimum distance a full power base station would need to be from a test point in order to comply with a given coordination threshold. To illustrate the impact of height gain we have included two lines for comparison: field strength measured at 15m and at 3m. 3m is the height of the test points we use in our analysis.

The EIRP is the same for WiMAX Hand held and WiMAX integrated into Notebook link budgets. The WiMAX results below are therefore valid for both Hand held and Notebook link budgets.

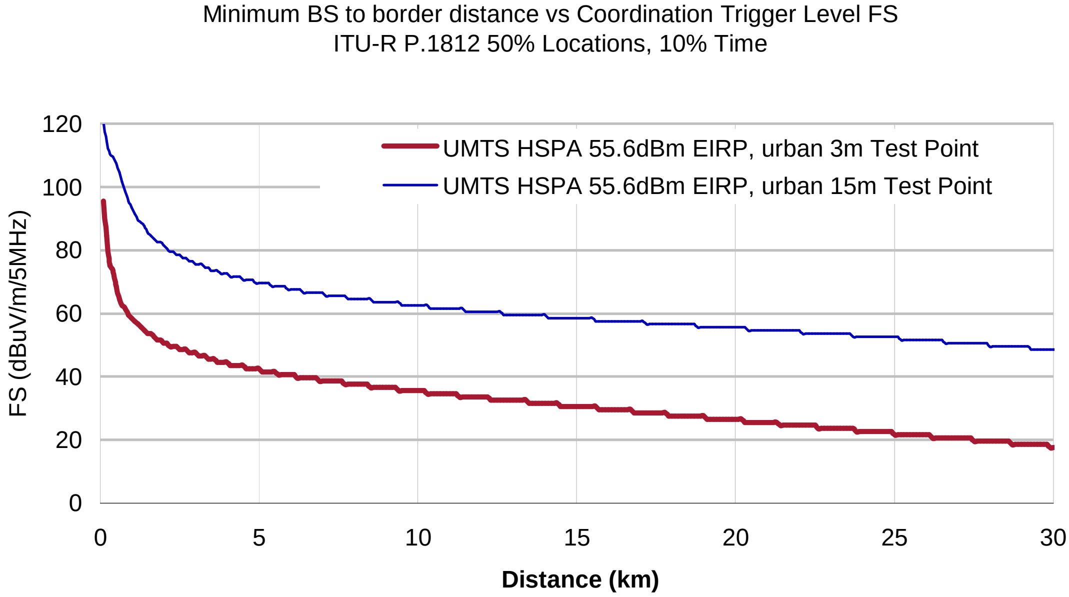


Figure 5.6: *Minimum Distance for UMTS HSPA Urban 15m Base station interferer, as a function of trigger value [Source: Analysys Mason]*

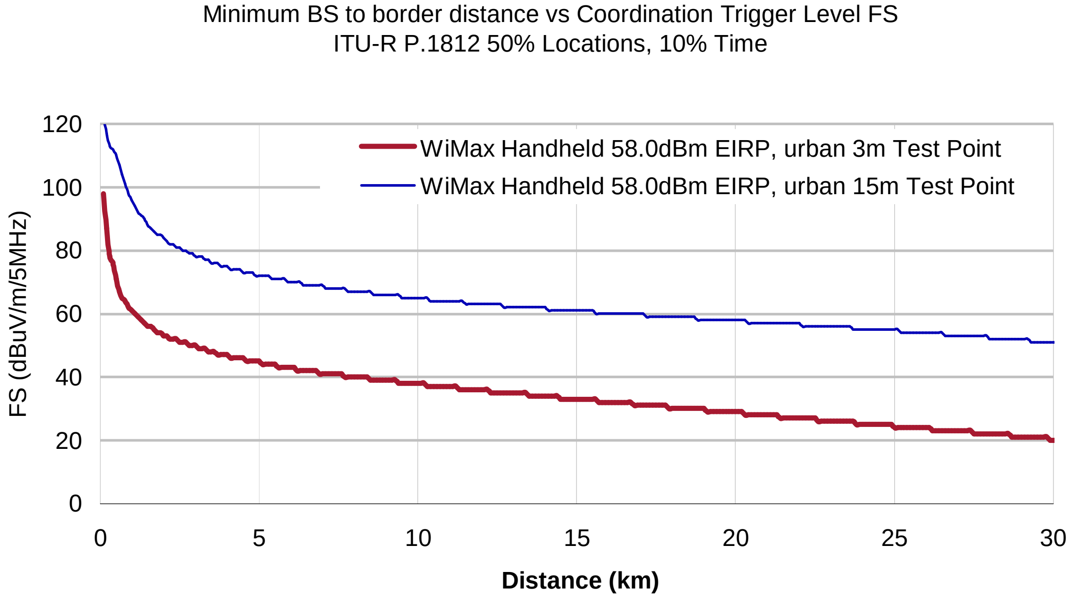


Figure 5.7: *Minimum distance for WiMAX Urban 15m Base station interferer, as a function of trigger level [Source: Analysys Mason]*

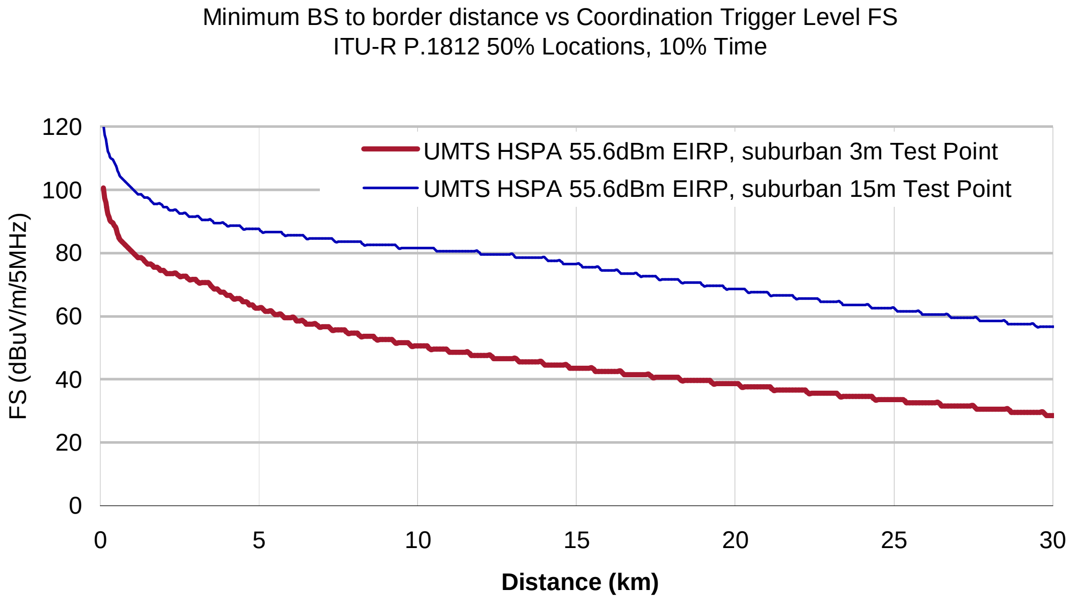


Figure 5.8: Minimum distance for UMTS HSPA suburban 20m Base station interferer, as a function of trigger level [Source: Analysys Mason]

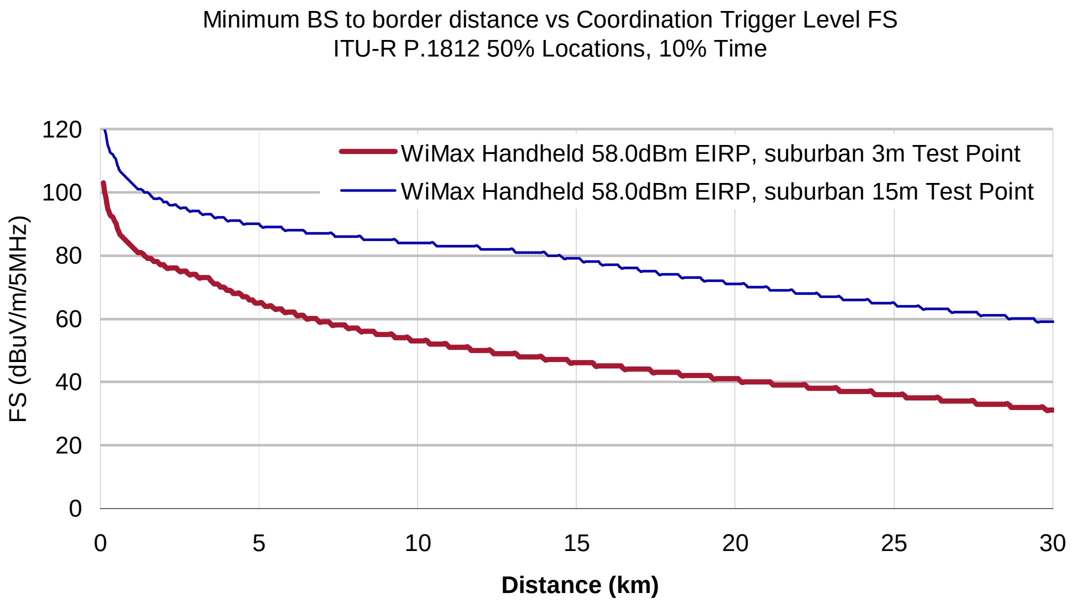


Figure 5.9: Minimum distance for WiMAX suburban 20m Base station interferer, as a function of trigger level [Source: Analysys Mason]

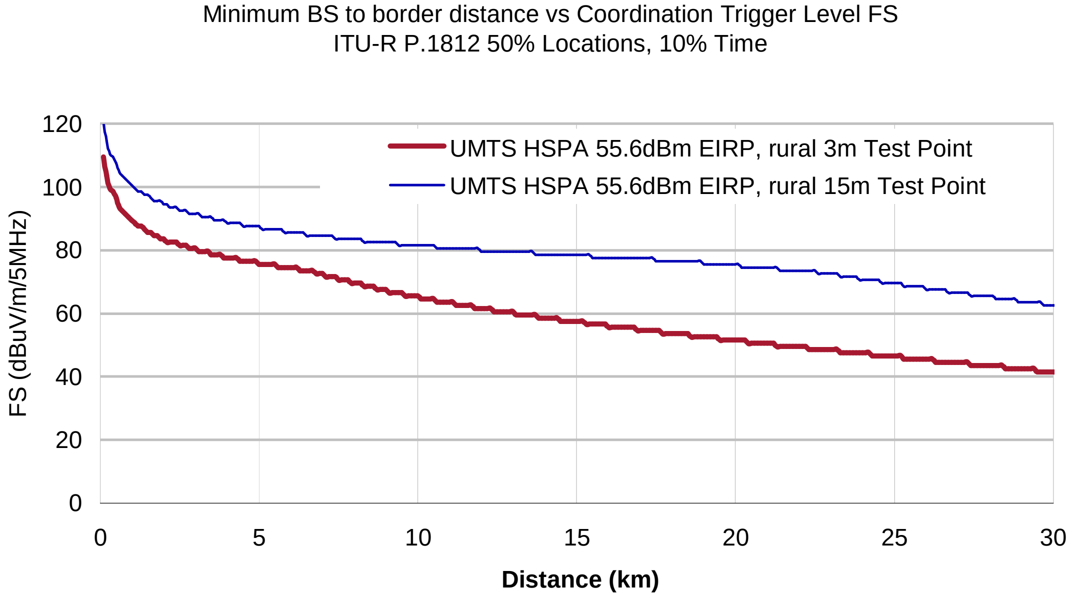


Figure 5.10: Minimum distance for UMTS HSPA rural 30m Base station interferer, as a function of trigger level [Source: Analysys Mason]

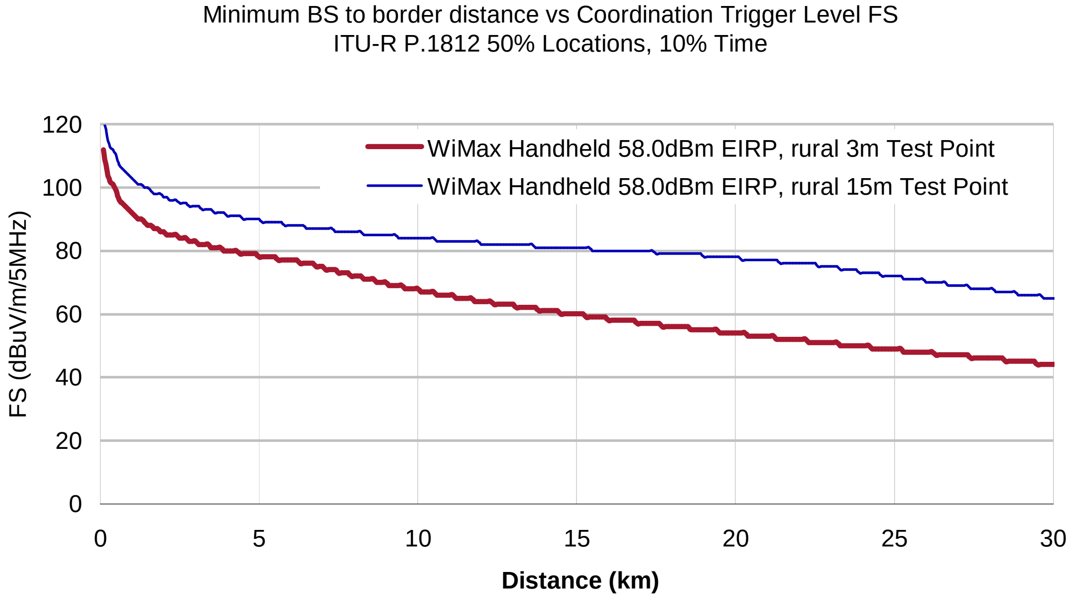


Figure 5.11: Minimum distance for WiMAX rural 30m Base station interferer, as a function of trigger level [Source: Analysys Mason]

5.2 Impact of trigger level on data throughput at victim and interferer

This section discusses the impact of the coordination trigger level on data throughput, both on the victim base station and on the interferer's subscriber unit. The impact on the victim arises as a result of an increase in interference and the corresponding impact on SINR, assuming the wanted signal is a subscriber at the cell edge with 50% (mean) signal fade.

Impact on the interferer is defined in terms of the data rate that can be delivered for a subscriber unit on the international border, within the constraints imposed by having to maintain emissions below the coordination threshold. This means that the wanted signal measured at 3m height must be no more than the coordination trigger level. We have calculated the equivalent signal strength at 1.5m (a typical user equipment (UE) height), using Rec. ITU-R P.1812.

In the following sets of results, it is assumed that, if the two lines cross at more than 0 Bps/Hz, it is possible for the interfering and victim cell edges to be co-incident at the international border, and for the two systems to operate without further mitigation (not withstanding the requirement to coordinate, if interference is above the trigger level).

If the two lines do not cross above 0 Bps/Hz then there needs to be some distance separation between the two systems, or the application of some interference mitigation technique in order for the systems to operate.

All trigger levels values are for 3m test points on the international border. Field strength is predicted with Rec. ITU-R P.1812 50 locations 10% time. BS and UE EIRP are as per the link budgets in Annexes A and B.

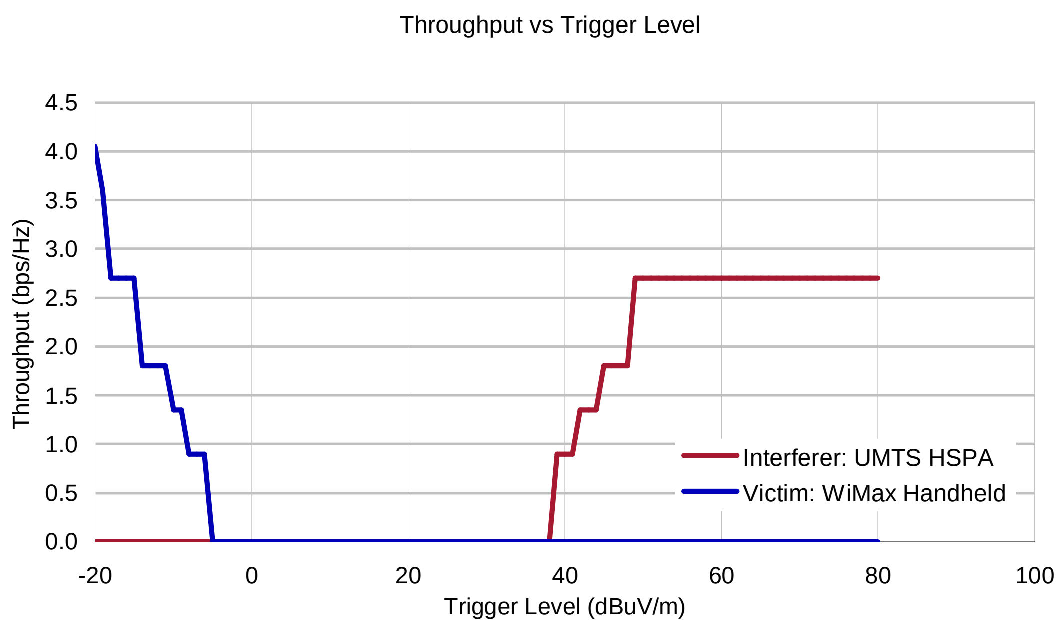


Figure 5.12: UMTS HSPA to WiMAX Handheld for urban [Source: Analysys Mason]

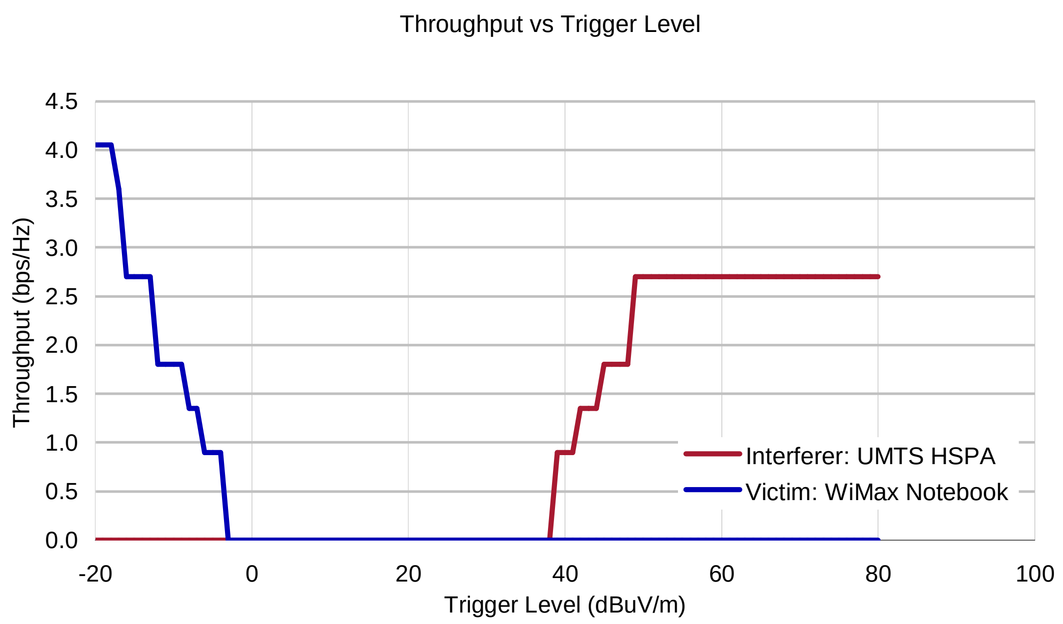


Figure 5.13: *UMTS HSPA to WiMAX Notebook for urban [Source: Analysys Mason]*

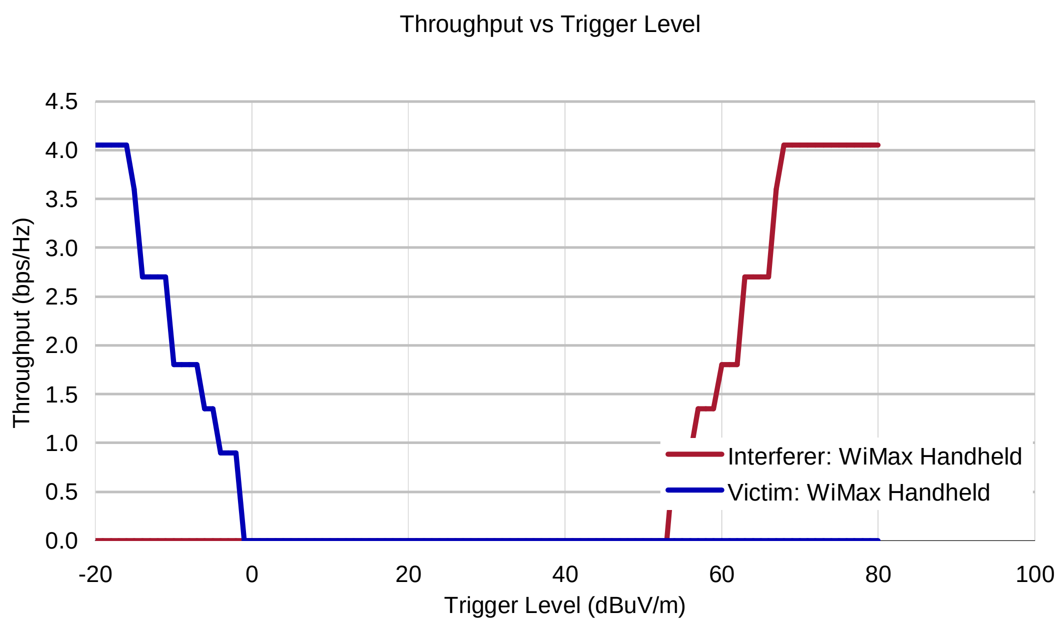


Figure 5.14: *WiMAX Handheld to WiMAX Handheld for urban [Source: Analysys Mason]*

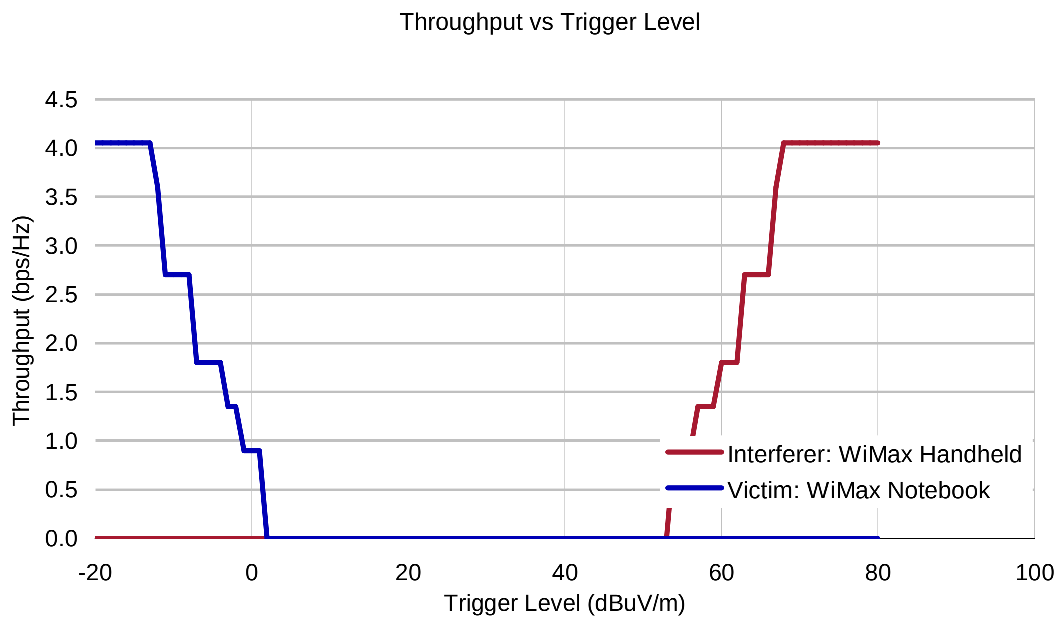


Figure 5.15: *WiMAX Handheld to WiMAX Notebook for urban [Source: Analysys Mason]*

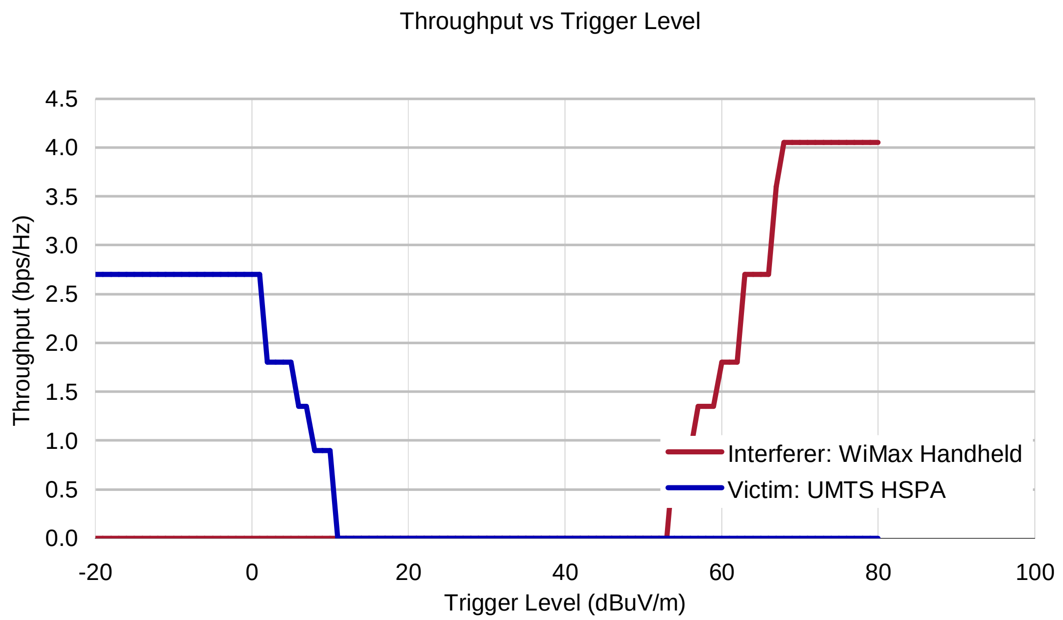


Figure 5.16: *WiMAX Handheld to UMTS HSPA for urban [Source: Analysys Mason]*

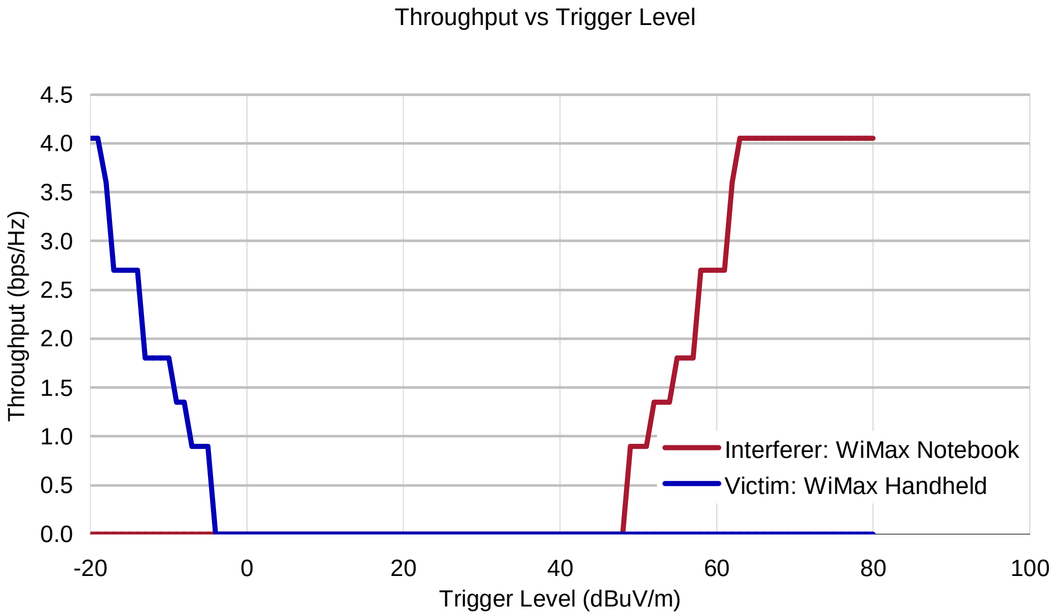


Figure 5.17: *WiMAX Notebook to WiMAX Handheld for urban [Source: Analysys Mason]*

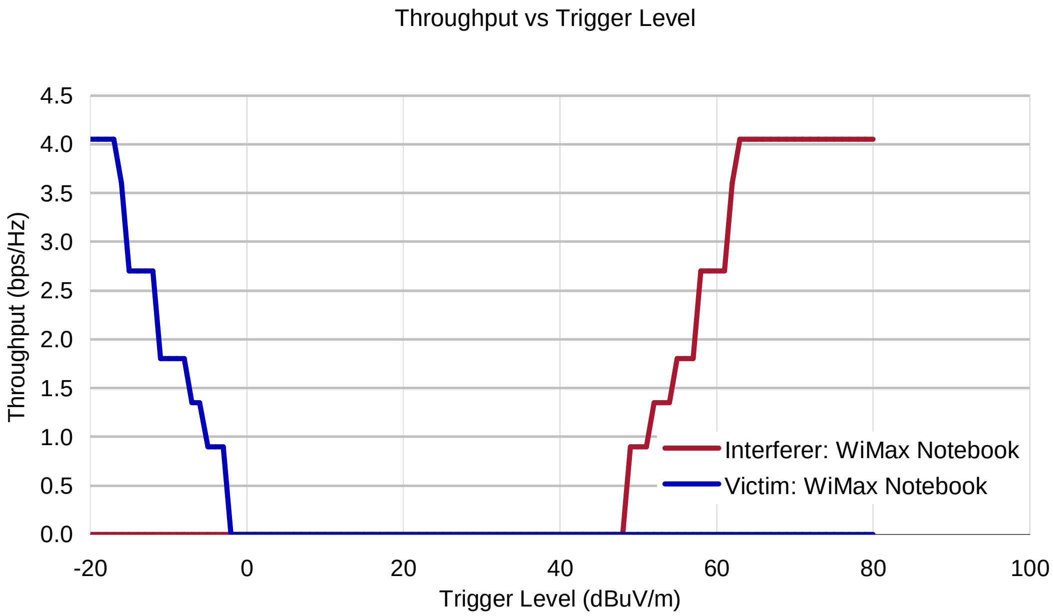


Figure 5.18: *WiMAX Notebook to WiMAX Notebook for urban [Source: Analysys Mason]*

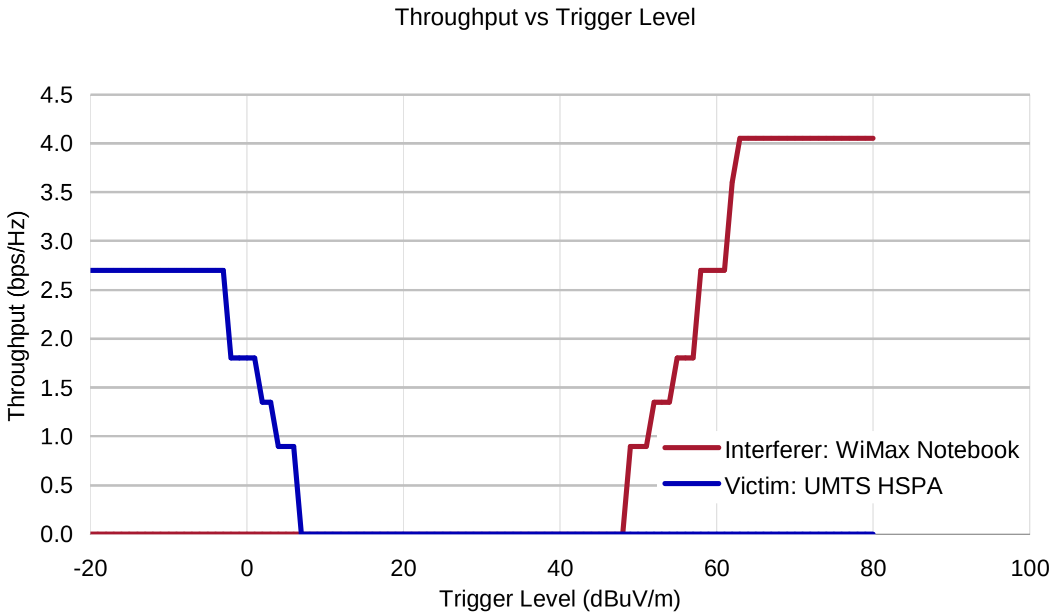


Figure 5.19: WiMAX Notebook to UMTS HSPA for urban [Source: Analysys Mason]

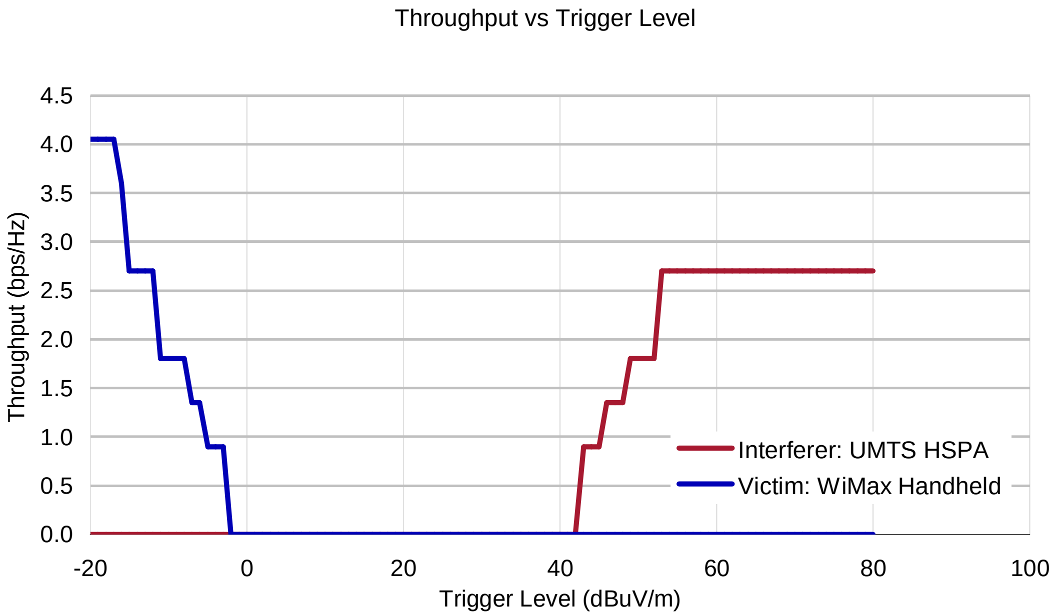


Figure 5.20: UMTS HSPA to WiMAX Handheld for Suburban [Source: Analysys Mason]

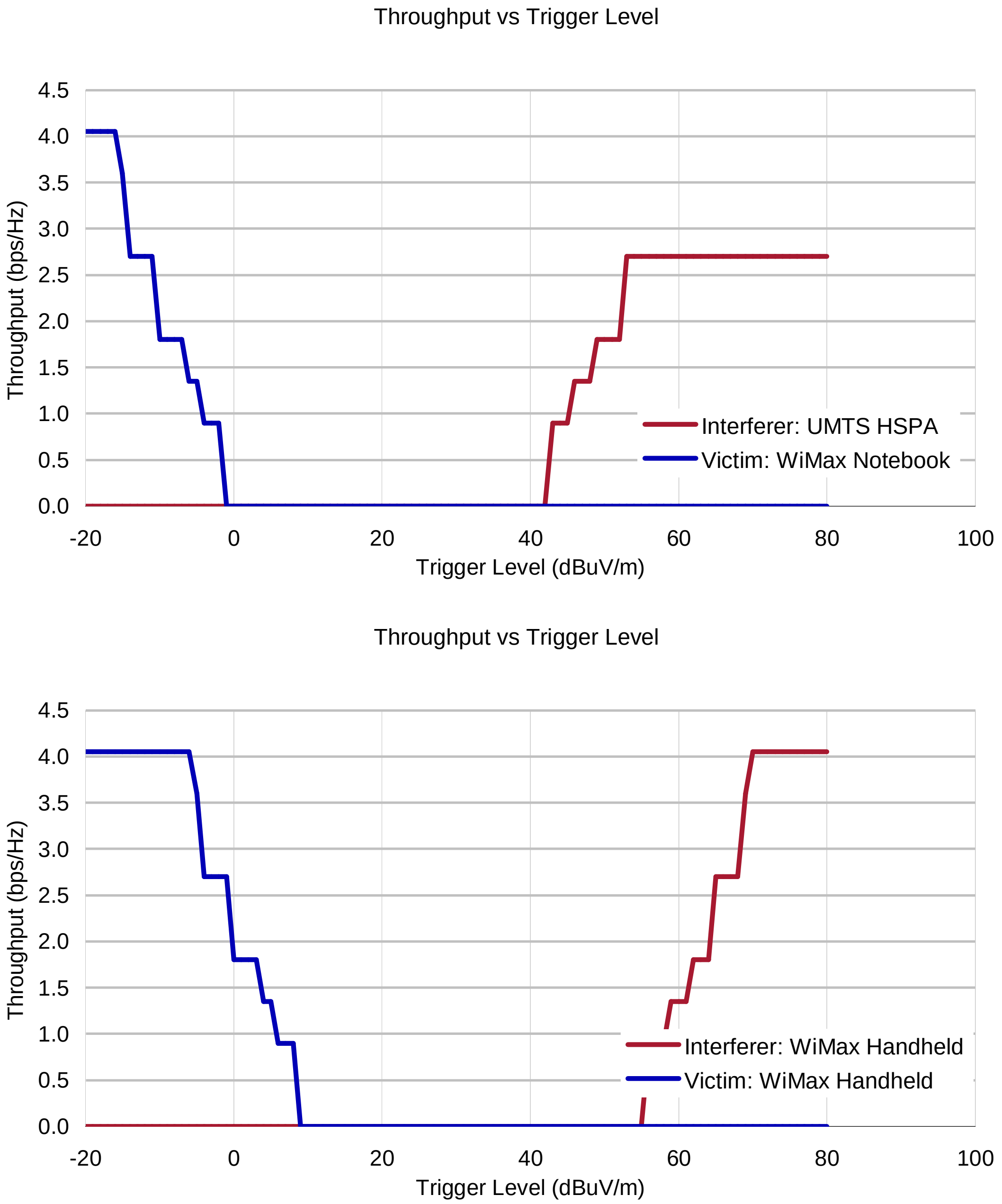


Figure 5.21: UMTS HSPA to WiMAX Notebook for Suburban [Source: Analysys Mason]

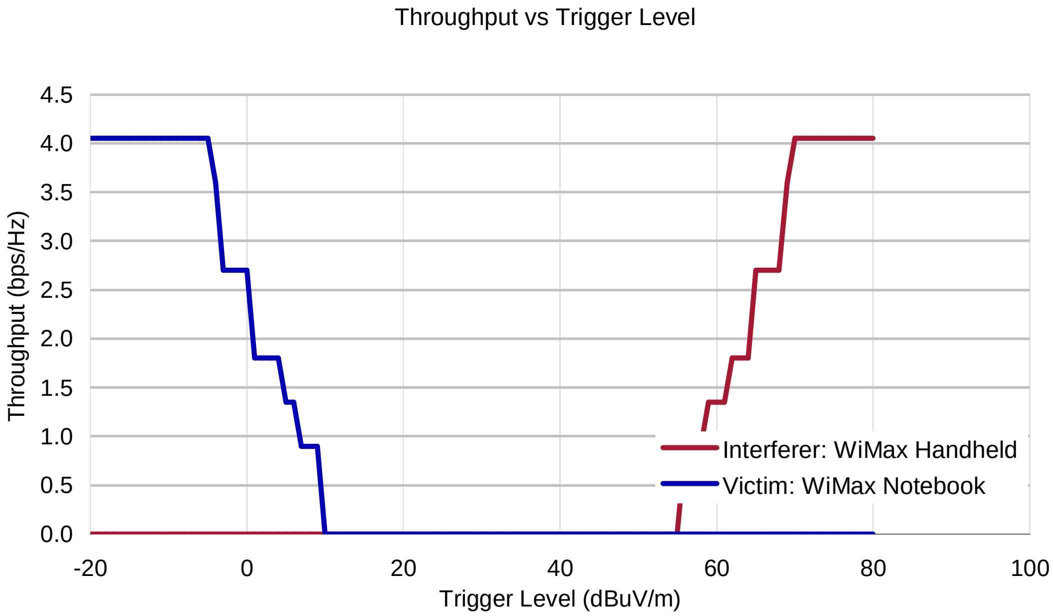


Figure 5.22: WiMAX Handheld to WiMAX Handheld for Suburban [Source: Analysys Mason]

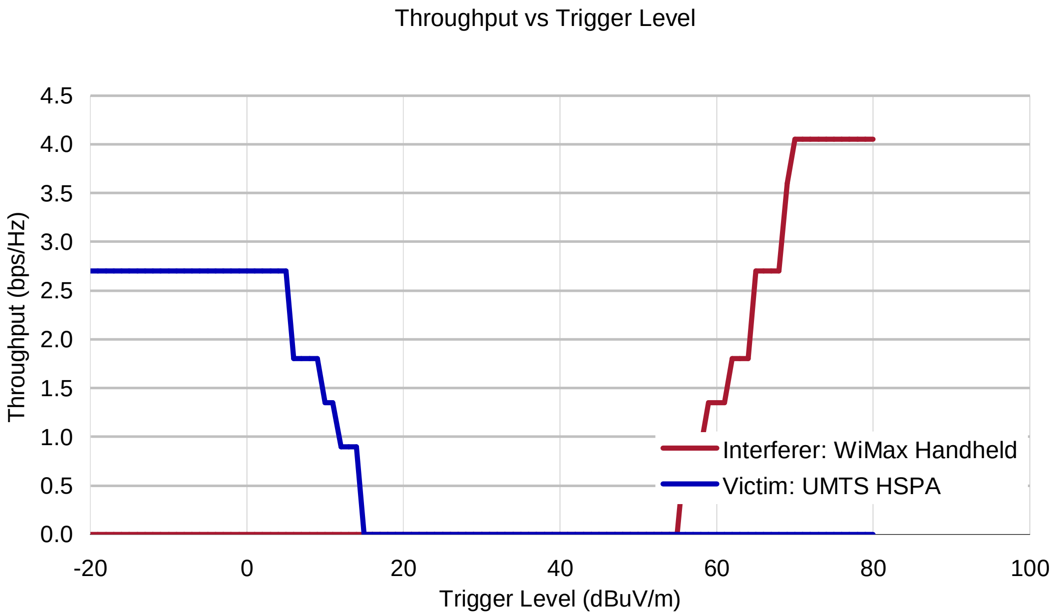


Figure 5.23: WiMAX Handheld to WiMAX Notebook for Suburban [Source: Analysys Mason]

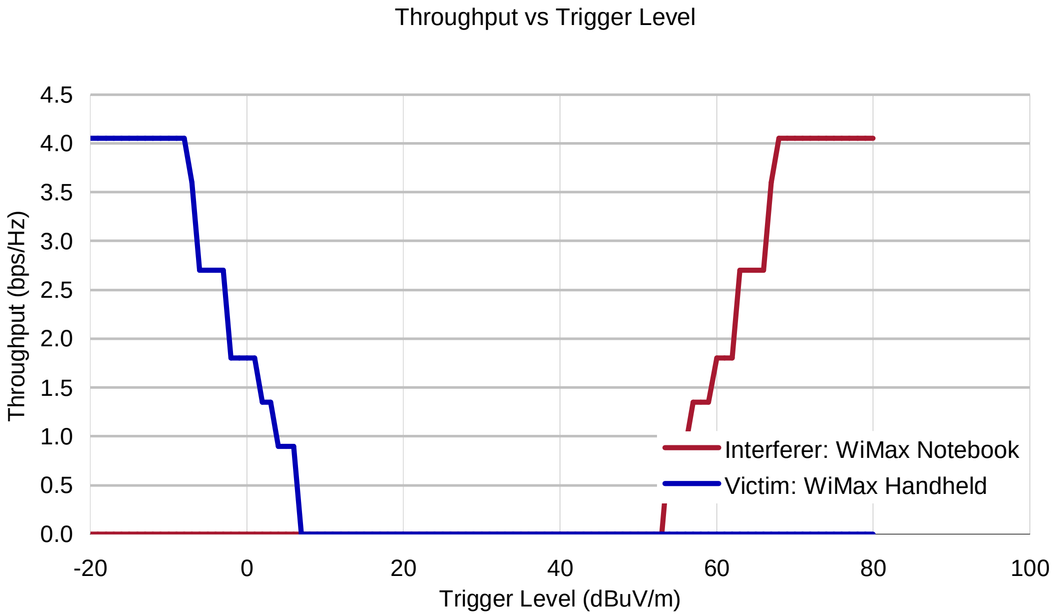


Figure 5.24: WiMAX Handheld to UMTS HSPA for Suburban [Source: Analysys Mason]

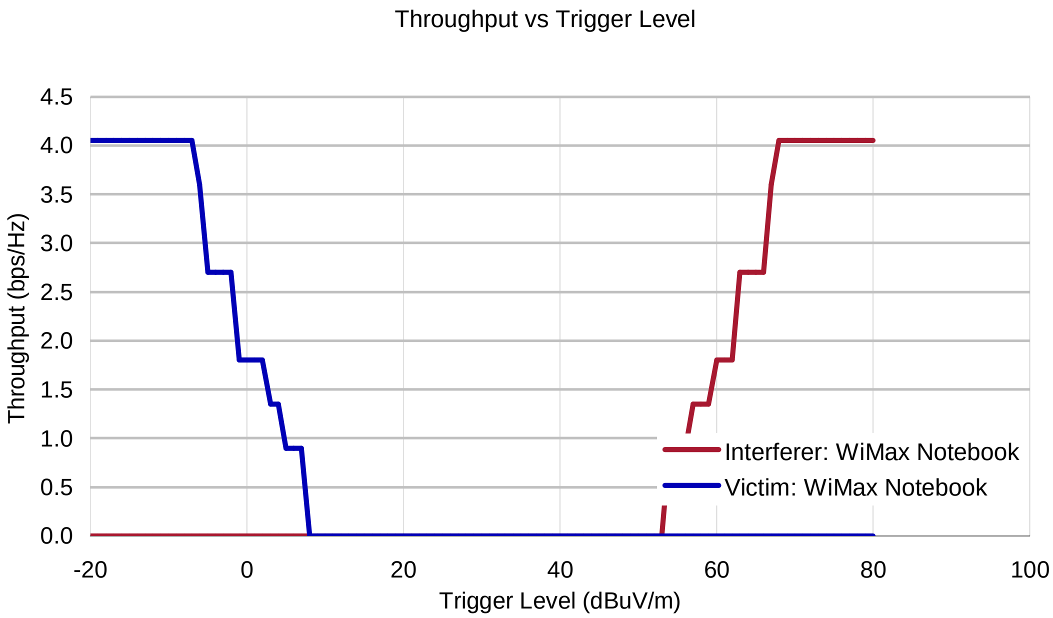


Figure 5.25: WiMAX Notebook to WiMAX Handheld for Suburban [Source: Analysys Mason]

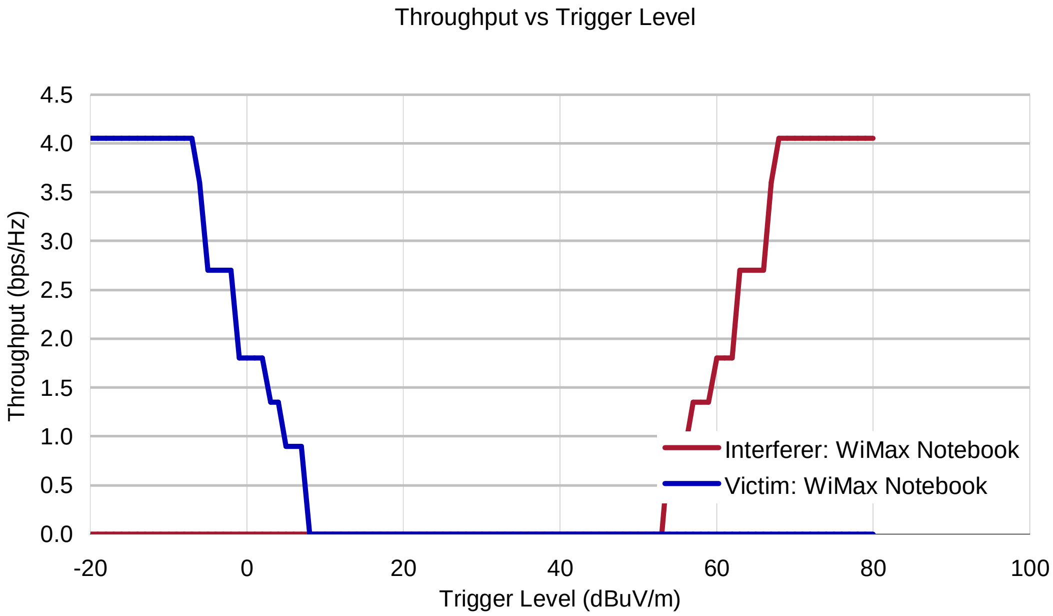


Figure 5.26: WiMAX Notebook to WiMAX Notebook for Suburban [Source: Analysys Mason]

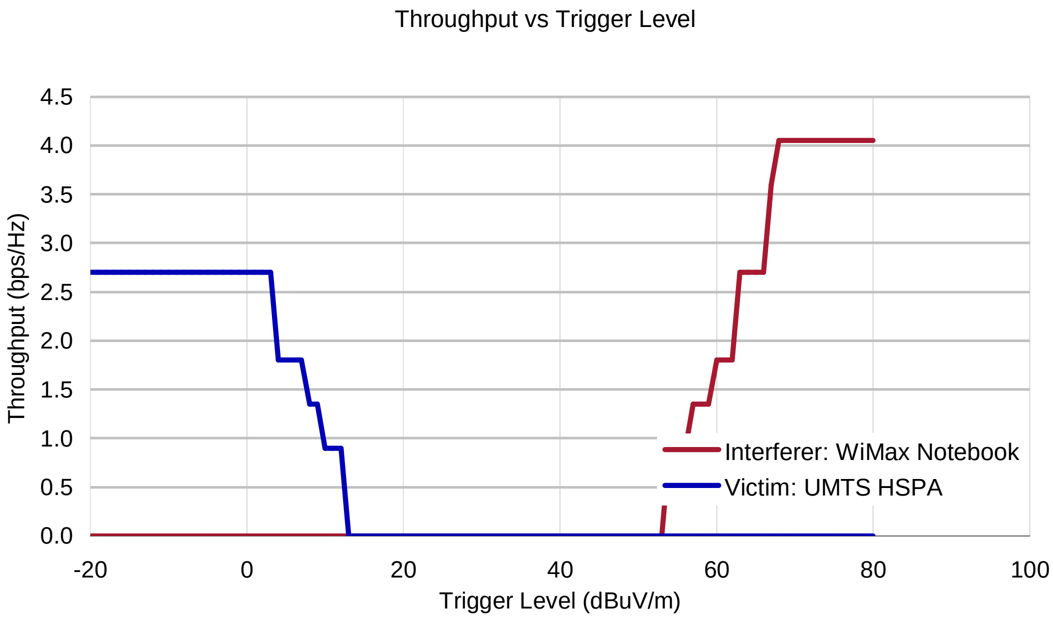


Figure 5.27: WiMAX Notebook to UMTS HSPA for Suburban [Source: Analysys Mason]

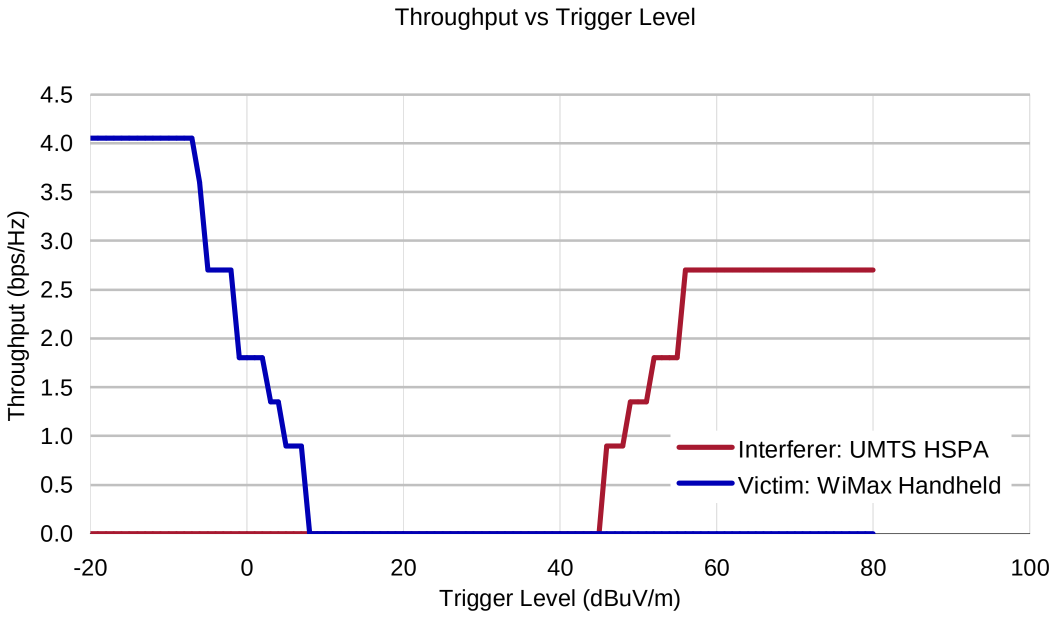


Figure 5.28: UMTS HSPA to WiMAX Handheld for Rural [Source: Analysys Mason]

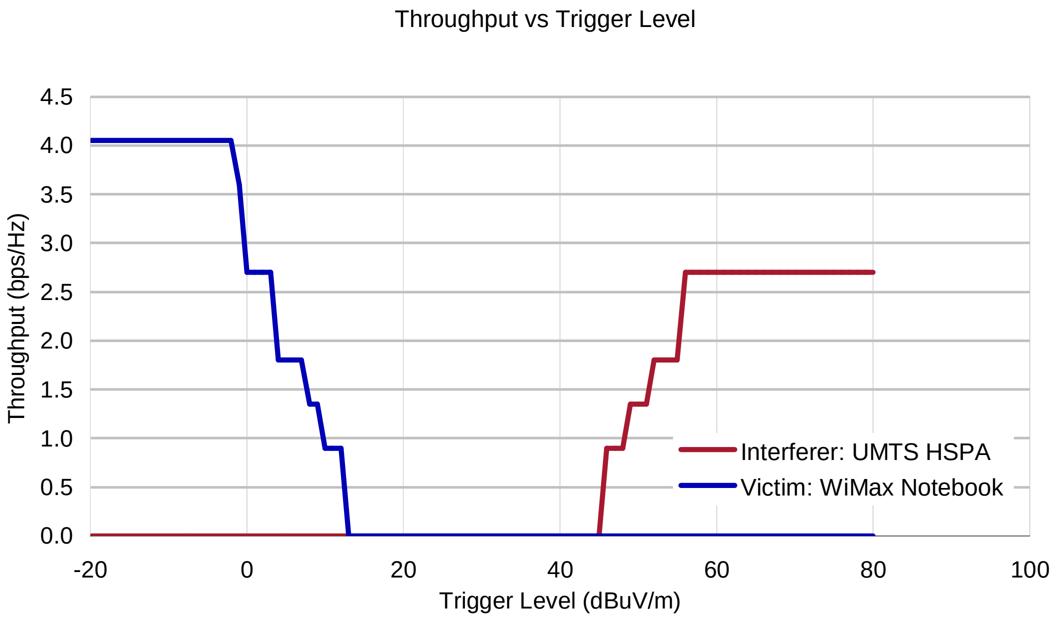


Figure 5.29: UMTS HSPA to WiMAX Notebook for Rural [Source: Analysys Mason]

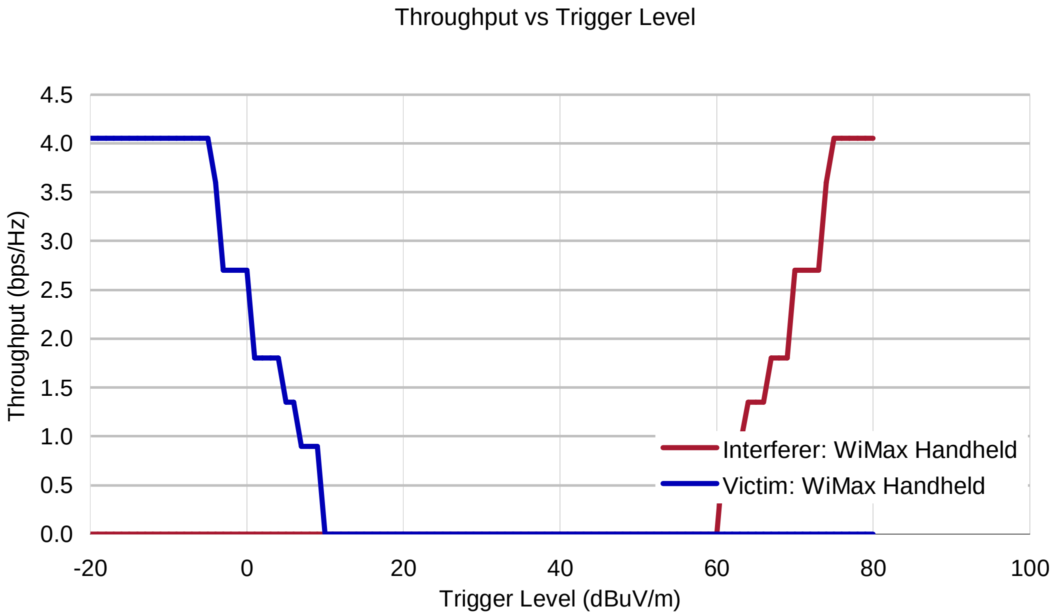


Figure 5.30: WiMAX Handheld to WiMAX Handheld for Rural [Source: Analysys Mason]

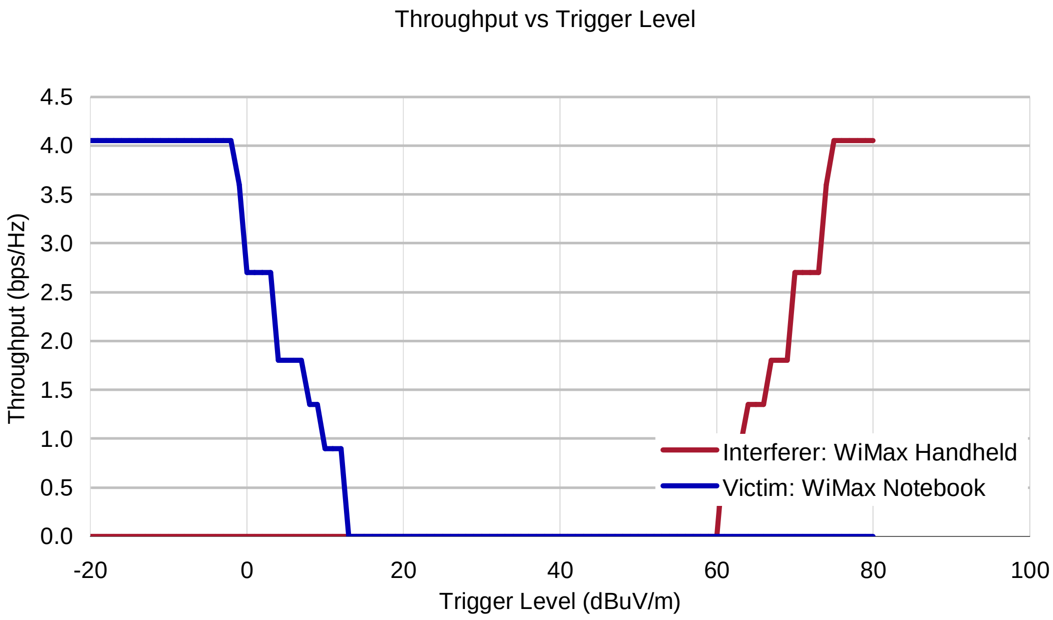


Figure 5.31: WiMAX Handheld to WiMAX Notebook for Rural [Source: Analysys Mason]

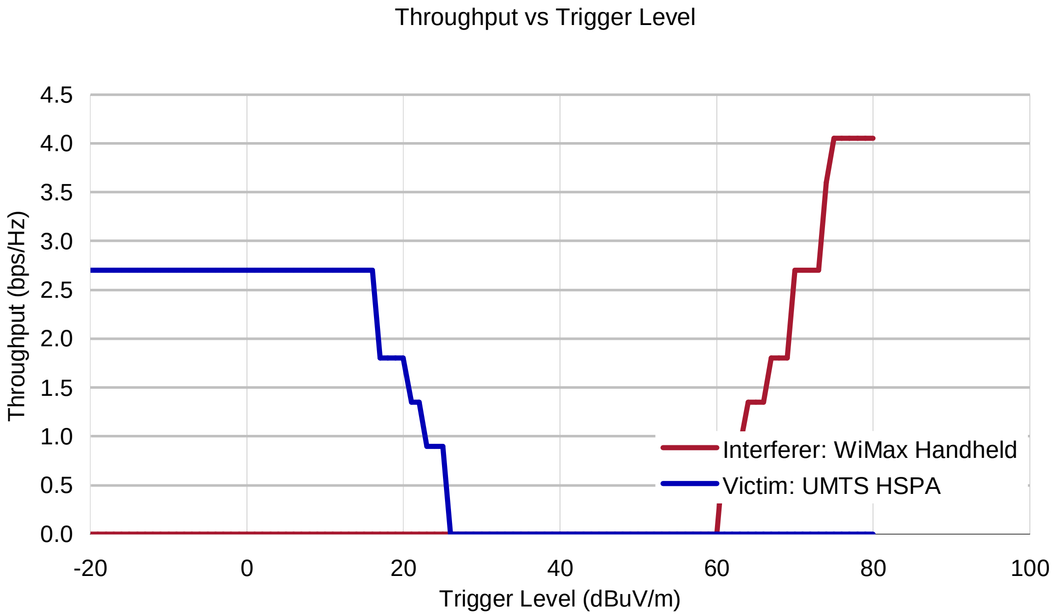


Figure 5.32: WiMAX Handheld to UMTS HSPA for Rural [Source: Analysys Mason]

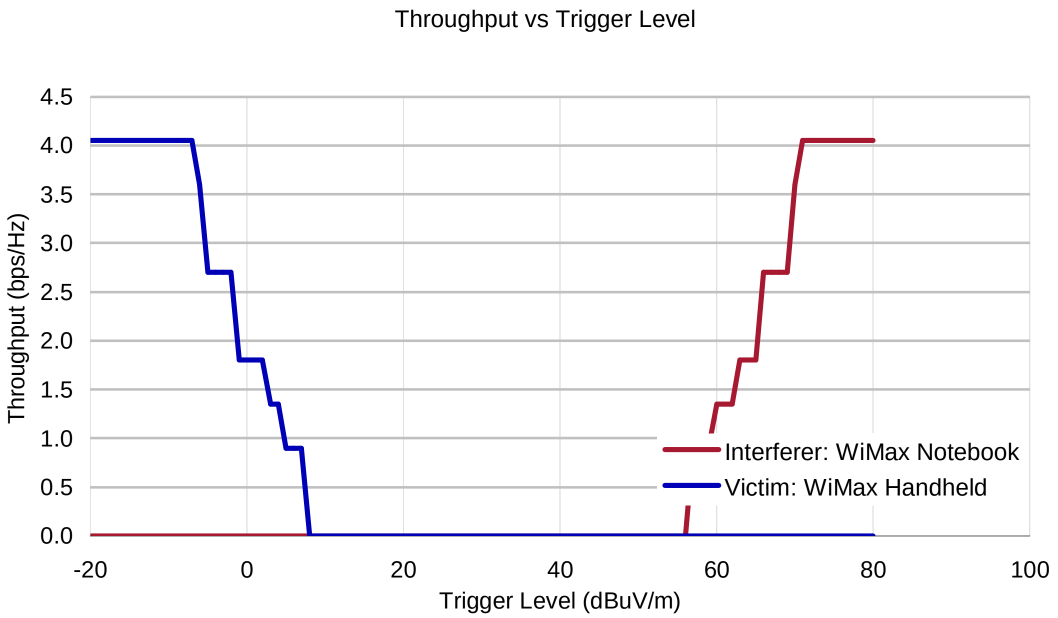


Figure 5.33: WiMAX Notebook to WiMAX Handheld for Rural [Source: Analysys Mason]

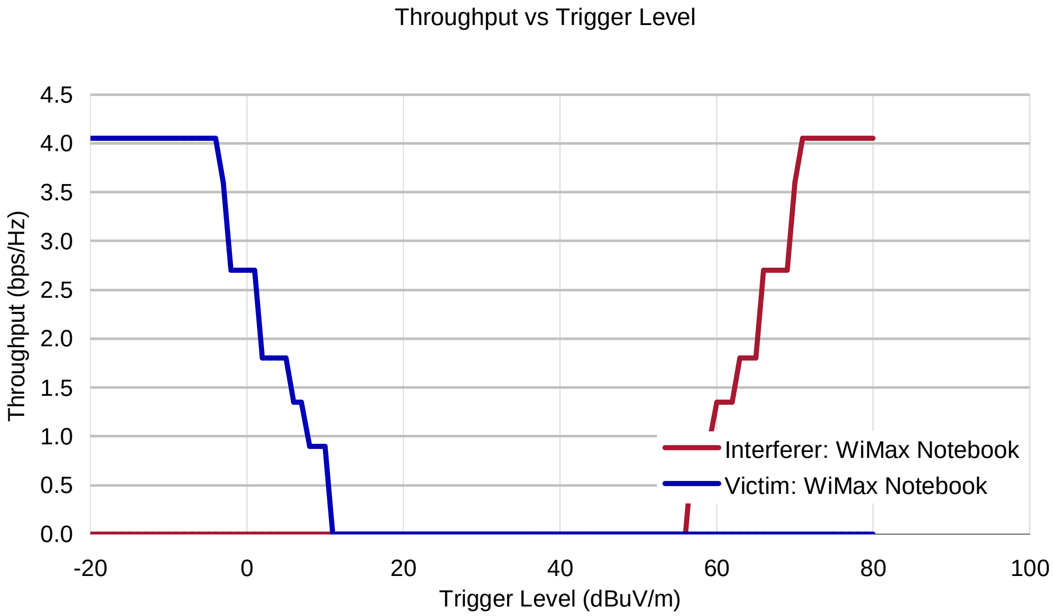


Figure 5.34: WiMAX Notebook to WiMAX Notebook for Rural [Source: Analysys Mason]

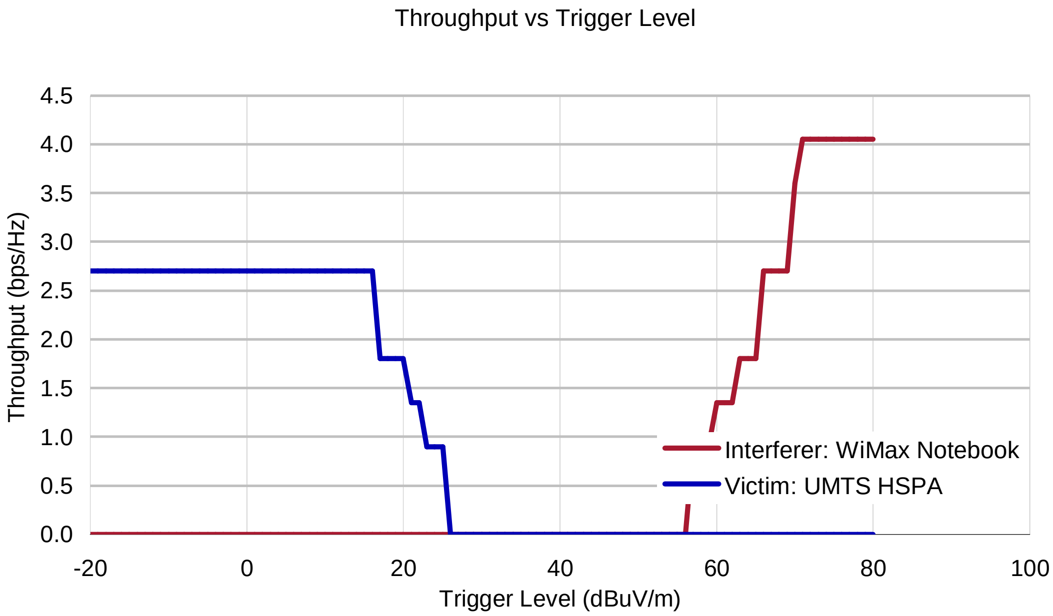


Figure 5.35: WiMAX Notebook to UMTS HSPA for Rural [Source: Analysys Mason]

5.3 Summary Results from Phase One

Figure 5.18 below shows a summary of results from Phase 1 of the modelling. The trigger level at 3m shows the result predicted with ITU-R P.1812 and represents the maximum field strength at the victim base station without exceeding its interference tolerance.

Scenario	*Environment*	*Interferer*	*Victim*	*Phase 1 ITU 1812 Trigger Level (3m) (dBuV/m/5MHz)*	*Max. Interfence FS allowed at BS antenna (dBuV/m/5MHz)*
1	urban	UMTS HSPA	WiMax Handheld	-5.44	22.56
2	urban	UMTS HSPA	WiMax Notebook	-3.44	22.56
3	urban	WiMax Handheld	WiMax Handheld	-1.44	22.56
4	urban	WiMax Handheld	WiMax Notebook	1.56	22.56
5	urban	WiMax Handheld	UMTS HSPA	10.81	24.81
6	urban	WiMax Notebook	WiMax Handheld	-4.44	22.56
7	urban	WiMax Notebook	WiMax Notebook	-2.44	22.56
8	urban	WiMax Notebook	UMTS HSPA	6.81	24.81
9	suburban	UMTS HSPA	WiMax Handheld	-2.44	22.56
10	suburban	UMTS HSPA	WiMax Notebook	-1.44	22.56
11	suburban	WiMax Handheld	WiMax Handheld	8.56	22.56
12	suburban	WiMax Handheld	WiMax Notebook	9.56	22.56
13	suburban	WiMax Handheld	UMTS HSPA	14.81	24.81
14	suburban	WiMax Notebook	WiMax Handheld	6.56	22.56
15	suburban	WiMax Notebook	WiMax Notebook	7.56	22.56
16	suburban	WiMax Notebook	UMTS HSPA	12.81	24.81
17	rural	UMTS HSPA	WiMax Handheld	7.56	22.56
18	rural	UMTS HSPA	WiMax Notebook	12.56	22.56
19	rural	WiMax Handheld	WiMax Handheld	9.56	22.56
20	rural	WiMax Handheld	WiMax Notebook	12.56	22.56
21	rural	WiMax Handheld	UMTS HSPA	25.81	24.81
22	rural	WiMax Notebook	WiMax Handheld	7.56	22.56
23	rural	WiMax Notebook	WiMax Notebook	10.56	22.56
24	rural	WiMax Notebook	UMTS HSPA	25.81	24.81

Figure 5.36: Summary of results from phase one [Source: Analysys Mason]

The difference in field strength predicted at the BS as opposed to at the test point should be noted from these results. As described in Section 4.1, this is due to:

- the different BS heights in the different environments (urban 15m, suburban 20m, rural 30m) (these are typical values for western Europe, excluding the UK); the use of Rec. ITU-R P.1812, and its treatment of a 3m receiver in these environments.
- the differing cell size for differing propagation environments (urban, suburban, rural), which determines the distance from a macro BS (interferer and victim) to the border.

Based on the results summarised in Figure 5.36, we have selected three trigger thresholds to be used as the starting point for analysis in Phase 2 of the study, which correspond to the worst case scenarios highlighted in yellow in the table above.

- WiMAX to WiMAX (non-synchronised): **-4dBµV/m/5MHz**
- UMTS HSPA to WiMAX: **-5dBµV/m/5MHz**
- WiMAX to UMTS HSPA: **7dBµV/m/5MHz.**

5.4 Effect of Interference Mitigation Techniques

As part of the study, the WiMAX Forum asked us to consider the effect of interference mitigation within wireless systems as a means of coordinating networks in border areas.

Interference mitigation techniques are used to reduce the amount of interference received by the victim base stations. As an illustration of the effect of interference mitigation, the non-coverage area between interfering base station and border is decreased as illustrated in Figure 5.37, and the victim base stations can operate at a higher interference level as illustrated in Figure 5.38. The two figures are just examples to show the effect of mitigation techniques.

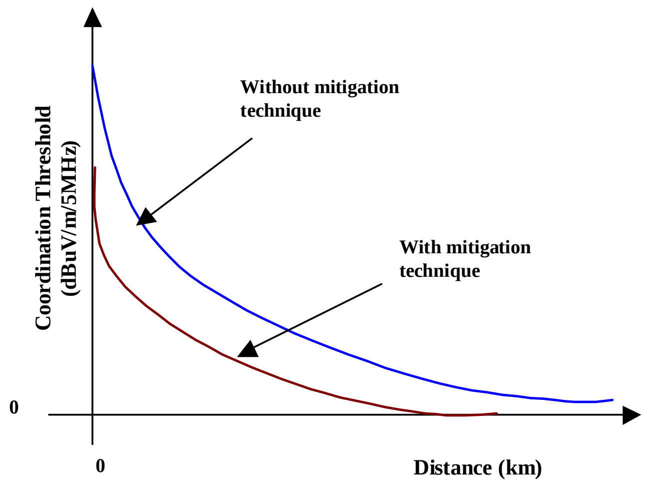


Figure 5.37: Impact of mitigation techniques on non-coverage area [Source: Analysys Mason]

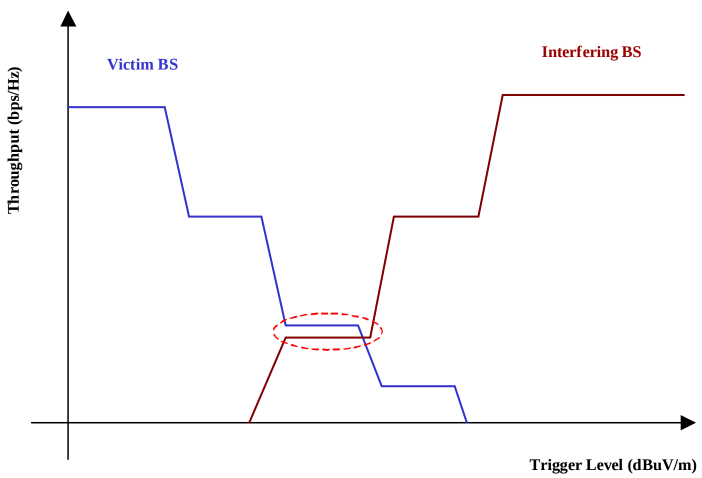


Figure 5.38: Impact of mitigation techniques on data throughput of Interfering and Victim base stations [Source: Analysys Mason]

The desired coordination threshold in Figure 5.38 will then be any point of the circled region of the two curves. This means that both base stations are operational at this range of trigger levels.

Mitigation techniques

► *Synchronisation*

This is a very powerful technique for removing base station to base station interference in TDD networks, such as WiMAX. The concept is simply to ensure that base stations do not transmit and receive at the same time (i.e. do not receive each others transmissions). To achieve this, the TDD downlink time slots on all base stations either side of an international border need to commence at the same instant, and be of the same duration. Synchronisation of starting points can be achieved by reference to a GPS time signal ensuring time slots are of the same length requires the two network operators to settle at the same uplink/downlink ratios.

In our modelling we have considered networks that are synchronised, and that are not synchronised, and we have concluded that it is appropriate to have two different coordination thresholds for these circumstances.

► *Antenna down tilt*

It is common practice to include a small down tilt on sectored antennas. This helps reduce creation of interference in to numbering cells, and exported interference into neighbouring countries. We have used a two degree down tilt as our base case, but have repeated the analysis with a six degree tilt to show how increase tilt reduces exported interference. This is shown as a second curve in our results in section 6.1.

► *Suppression of secondary lobes on upper half of antenna pattern*

Sectored antennas suppress the secondary lobes on the upper half of the elevation pattern. This is so that when the antenna is down tilted the secondary lobe does not generate or receive excessive interference. This is illustrated in the figure below. We have use the antenna pattern below in all of our analysis, with a two degree tilt (as shown) and a six degree tilt.

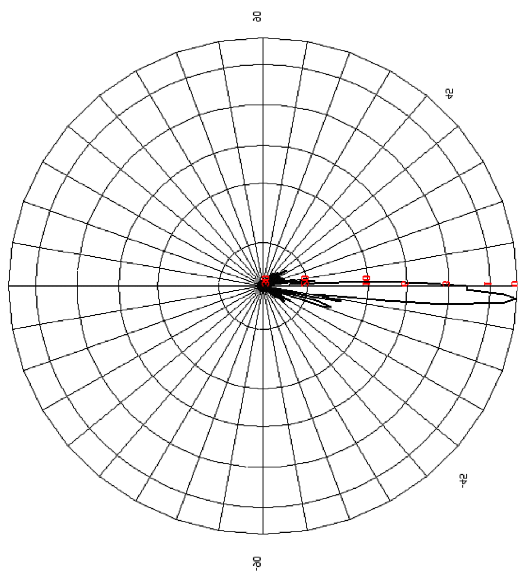


Figure 5.39: Antenna elevation pattern showing suppressed upper secondary lobe and two degrees down tilt

► *Consideration of Antenna Azimuth*

In international border regions, care is taken not to point antennas directly at the closest point of the border. We have avoided such azimuths in our reference networks to reflect this practice. Once network operators enter into a coordination process and share knowledge of precise base station locations and predicted levels of interference, further azimuth changes may be made to mitigate particular base to base interference paths.

► *Site Placement*

Once network operators enter into coordination and share knowledge of precise base station locations and predicted levels of interference it may be possible to change base station locations in order to increase distance between interfering and victim stations. This may be practical if the coordination process begins whilst both operators are still at the initial stages of network design, and before site acquisition has commenced. However, once sites have been built such changes are expensive.

► *Reduced EIRP*

It may be practical to reduce the maximum base station EIRP to reduce interference. In our modelling we have reduced BS EIRP to the point where uplink and downlink paths have an equal maximum allowable path loss, (i.e. a balanced link budget). We have shown a further 3dB reduction in EIRP on a second curve of our results in section 6.1.

► *Frequency planning*

If a network is able to use multiple channels (as is the case with WiMAX), it may be practical to plan frequency use in light of international interference. For example, if an operator has 3x10MHz, and 20MHz of this is co-channel with WiMAX networks in neighbouring countries, whilst 10MHz is co-channel with UMTS, it may be practical to use the 10MHz is co-channel with UMTS on sectors that point away from the neighbouring countries, and perhaps towards the coast.

► *Partial Frequency Reuse*

Partial frequency re-use (dynamic or static) is a technique deployed in WiMAX networks to reduce cell-to-cell interference. Handsets with low path losses use the full channel band, but at reduced power, whilst handsets with high path losses use only a proportion of the channel (typically one third). The selection of frequencies is such that at the edges of adjacent cells, co-channel interference is reduced. This scheme can be extended across borders where networks share the same technology (i.e. WiMAX). Thus, partial frequency re-use reduces the base station power output, and thus reduces exported interference. It may be possible to reduce the EIRP value used in interference coordination where the interferer deploys partial frequency reuse. However, the precise amount of this reduction depends upon the dynamics of the system. Also, the victim system may still suffer interference if a selection of sub-carriers is on full power, even if the average channel power is greatly reduced. Due to these complexities we have not attempted to model partial frequency reuse in detail, but we have shown a third curve on our results that equates to a 3dB reduction in interference power.

6 Case Study of the Impact of Proposed Trigger Values and Interference Mitigation in a European Border Area

This section describes the results of Phase 2 of our analysis, where we modelled the effect of cross border coordination on a range of scenarios typical of network operation in real European border areas.

6.1 Percentage of sites requiring coordination versus coordination threshold

For each of the reference networks described in Section 4.2 of this report, we considered what percentage of sites within 40km from the border would need to be modified (power reduced, azimuth changed, town tilt increased etc.) **OR** be subject to the coordination process. We show this for a range of trigger threshold values from -10 to 60 dBμV/m/5Mhz.

In each figure we have shown the base case (EIRP as per link budgets and a two degree down tilt), and the effect of two mitigation techniques: six degree antenna down tilt and a 3dB power reduction.

The 3dB power reduction could be achieved by application of a number of mitigation techniques, for example by reducing EIRP directly; by an azimuth change, or by fractional frequency reuse. As one can see, the impact of a 1dB change in EIRP is equivalent to a 1dB change in coordination trigger threshold, whilst the application of down tilt has a more complex effect.

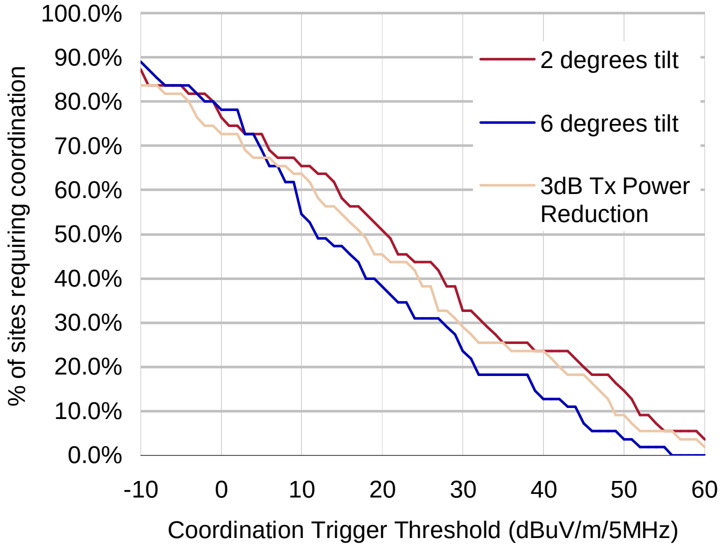


Figure 6.1: UMTS to WiMAX Notebook example (France to Switzerland) Analysys Mason

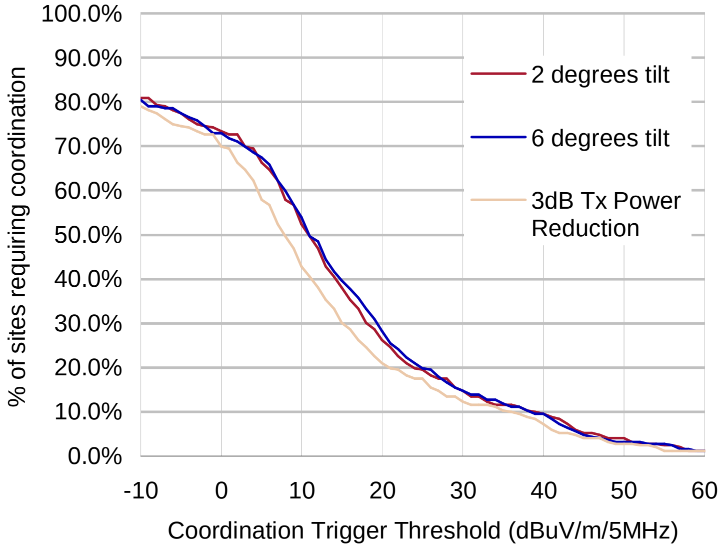


Figure 6.2: WiMAX HH to UMTS example (Germany to France) Analysys Mason

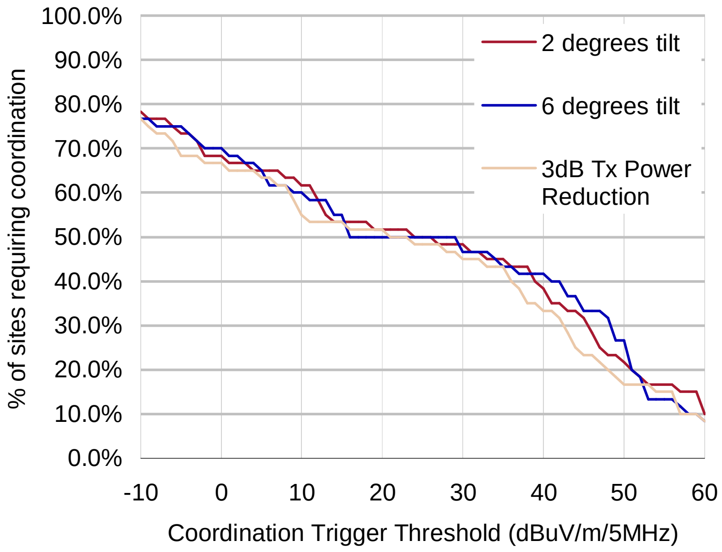


Figure 6.3: WiMAX HH to WiMAX Notebook (Germany to Switzerland) Analysys Mason

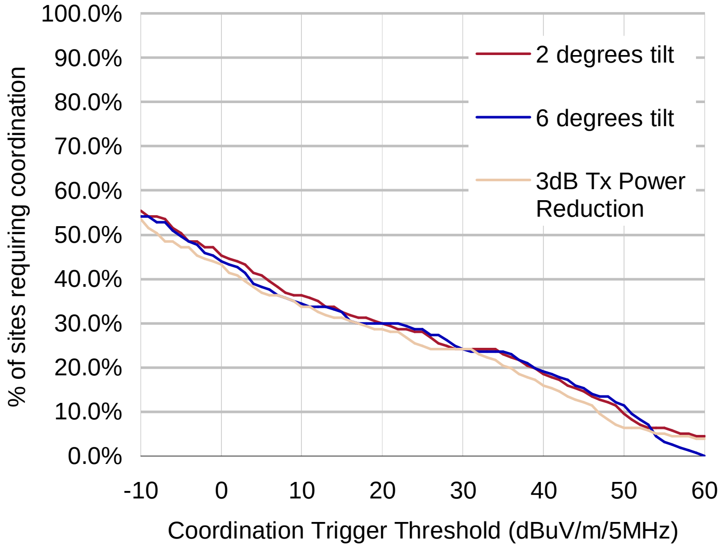


Figure 6.4: WiMAX Notebook to UMTS (Switzerland to France) Analysys Mason

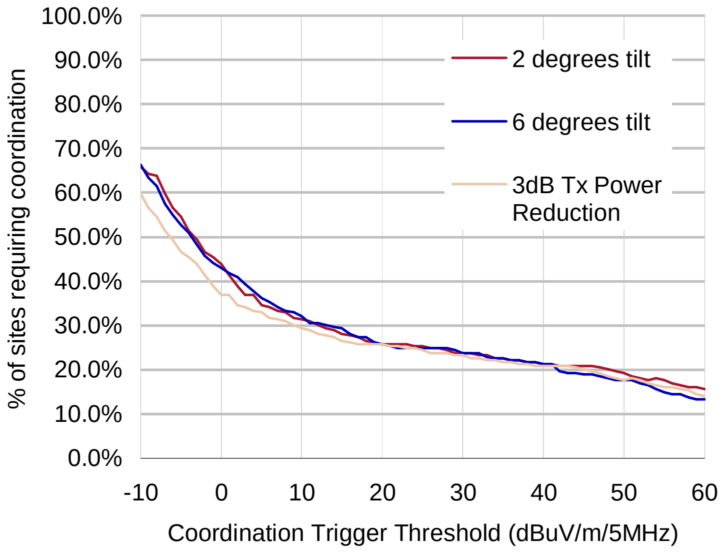


Figure 6.5: WiMAX Notebook to WiMAX Hand Held example (Switzerland to Germany) Analysys Mason

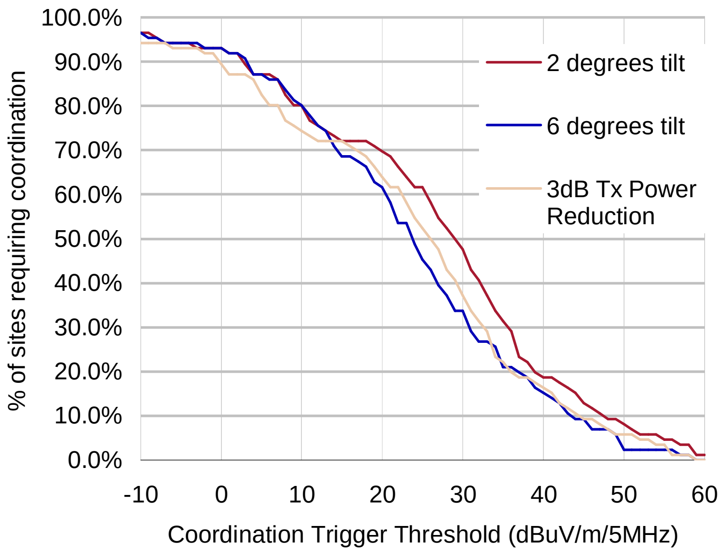


Figure 6.6: UMTS Notebook to WiMAX Hand Held example (France to Germany) Analysys Mason

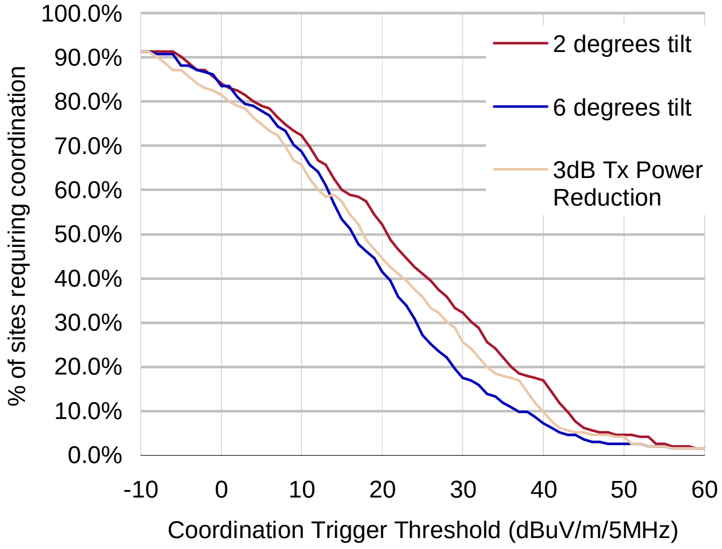


Figure 6.7: UMTS to WiMAX Notebook example (Belgium to Netherlands) Analysys Mason

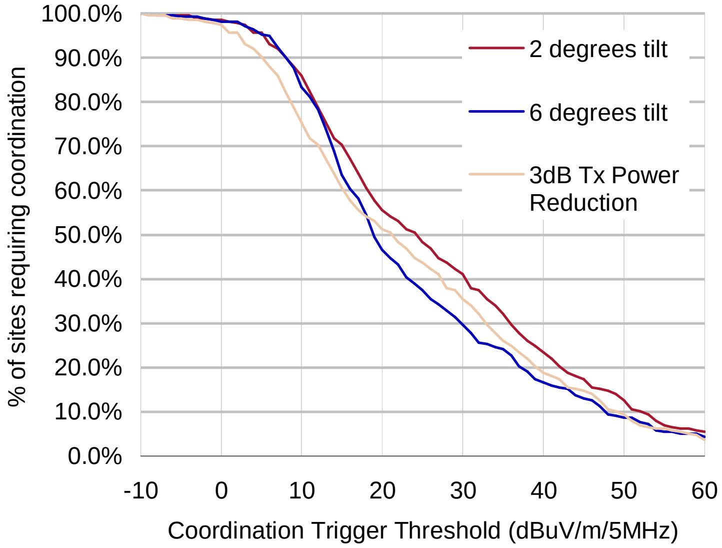


Figure 6.8: WiMAX Notebook to UMTS example (Netherlands to Belgium) Analysys Mason

From the above figures, one can see that the most significant effect on the percentage of sites requiring coordination is the ratio of urban to rural area and the position of the urban area with respect to the border. The small difference in WiMAX and HSPA trigger thresholds has only a second order effect.

6.2 Interference received at victim BS versus coordination trigger level (BS to BS without synchronisation)

In Figure 6.9 to Figure 6.14, sectors that breach the coordination threshold are removed from the interfering reference network, and the sum of interference at all victim base stations within 40km of the border is calculated. This has been repeated for a range of coordination trigger values. **The red line shows the maximum interfering field strength at the base station antenna that is allowed for within the relevant link budget.** The interference received at each base station is shown from lowest to highest, thus the charts show the Cumulative Distribution Function of the Bonn power sum of received interference.

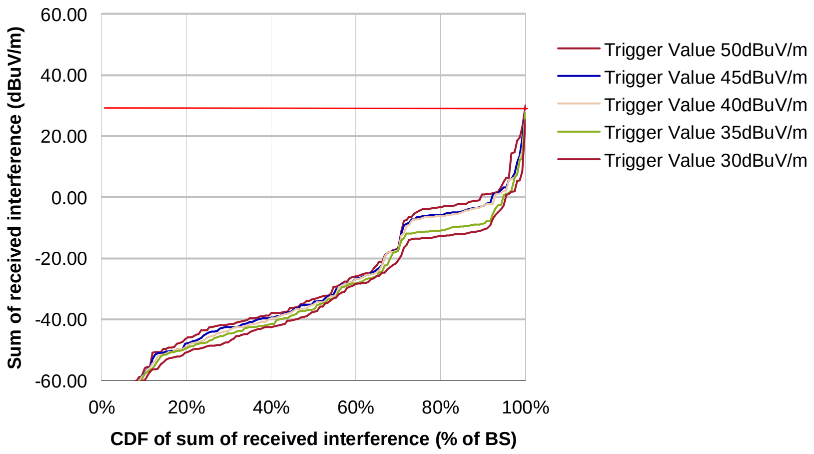


Figure 6.9: UMTS to WiMAX Notebook CDF of sum of received interference against Coordination Trigger Value (France to Switzerland) Analysys Mason

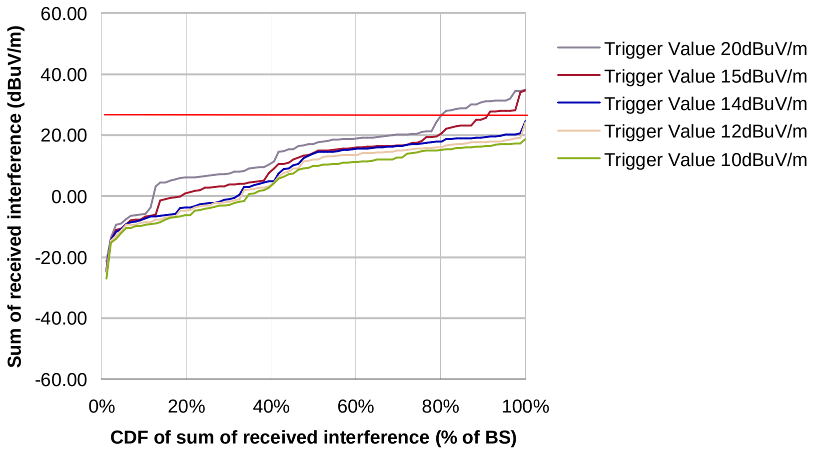


Figure 6.10: WiMAX HH to UMTS Notebook CDF of sum of received interference against Coordination Trigger Value (Germany to France) Analysys Mason

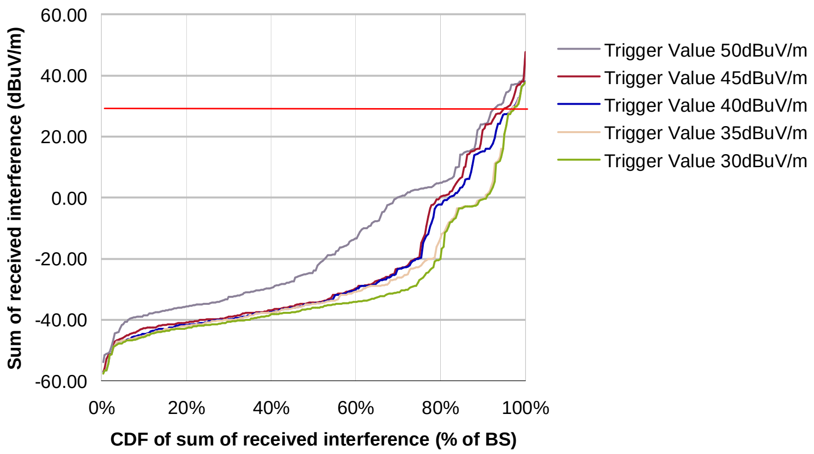


Figure 6.11: WiMAX HH to WiMAX Notebook CDF of sum of received interference against Coordination Trigger Value (Germany to Switzerland) Analysys Mason

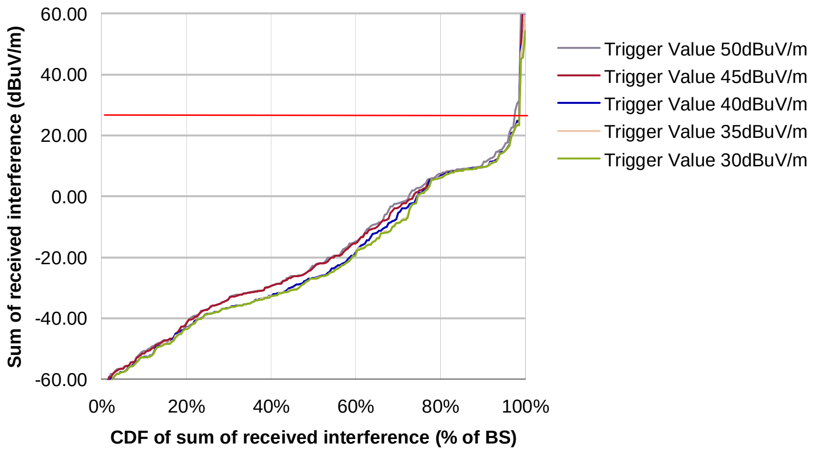


Figure 6.12: WiMAX Notebook to UMTS CDF of sum of received interference against Coordination Trigger Value (Switzerland to France) Analysys Mason

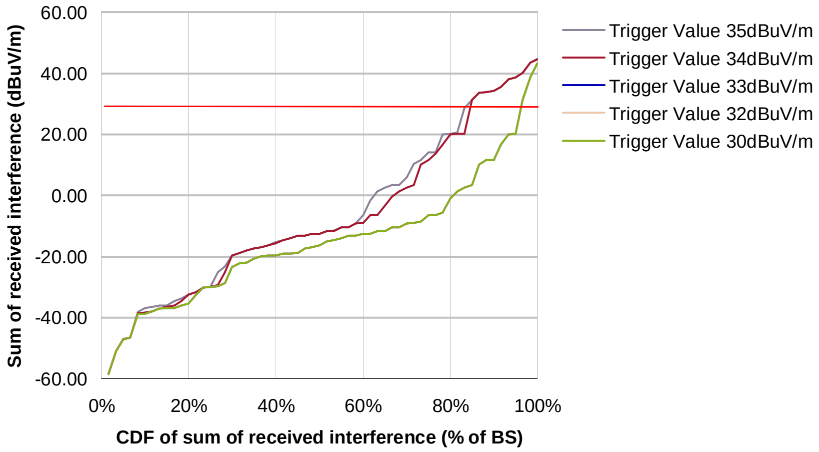


Figure 6.13: WiMAX Notebook to WiMAX Hand Held Notebook CDF of sum of received interference against Coordination Trigger Value (Switzerland to Germany) Analysys Mason

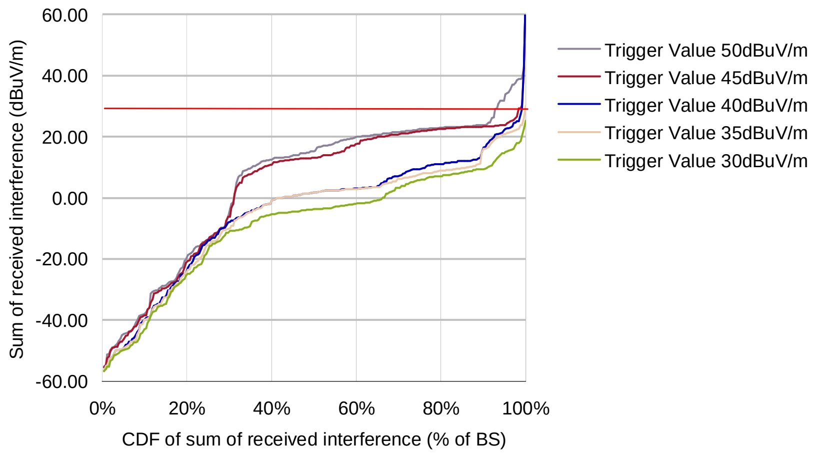


Figure 6.14: UMTS Notebook to WiMAX Hand Held CDF of sum of received interference against Coordination Trigger Value (France to Germany) Analysys Mason

From these charts we observe that the trigger levels determined by the worst case site general model in phase one are too low. As we are predicting interference at full EIRP and for only 10% of time, it would be reasonable to select a trigger level that results in a small number of breaches at base stations in the worst scenario above; we have used a figure of 5% of sites breached for 10% if time (i.e. 95% sites free from degrading interference for 90% of time). Thus as a result of our phase two modelling we have revised the trigger levels as follows:

- WiMAX to WiMAX (Co-channel, no synchronisation): 30dBμV/m/5MHz
- UMTS to WiMAX (Co-channel): 30dBμV/m/5MHz
- WiMAX to UMTS (Co-channel): 14dBμV/m/5MHz

The increase in trigger level is due to the following factors, which we assessed in full in Phase 2, that were not considered in Phase 1:

- Antenna pattern losses (tilt and azimuth).
- Terrain losses.
- Real scenarios represent a mixture of urban, suburban and rural regions.

When aggregated interference is at the limit we have adopted at the base station, this will only impact signals from mobiles on the edge of cell suffering the maximum fade allowed for in the link budget.

We also observed that interference levels where controlled by a relatively small percentage of test points. Figure 6.15 below illustrates this point: the figure shows paths from each base station (black dot) to the nearest test point (red dot).

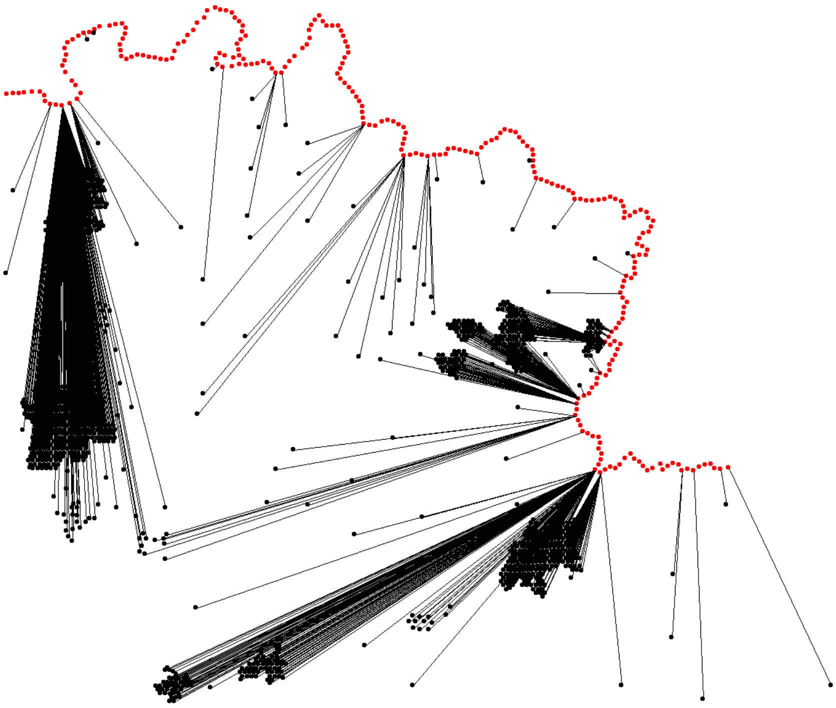


Figure 6.15: Base Station to nearest test point (Netherlands Belgium border) [Source: Analysys Mason]

6.3 BS to UE interference

In the case of TDD networks operating on either side of the border that are synchronised (in terms of frame and up/down link length), this completely removes BS to BS interference as no two BS are transmitting and receiving at the same time.

Where such synchronisation is applied, interference from BS to UE then becomes the limiting factor. In our Phase 2 analysis, we therefore modelled this scenario to illustrate the impact of interference to UE in the victim network when networks are synchronised to avoid BS-BS interference occurring.

As the UE is less sensitive than the base station (due to lower antenna gain) and therefore requires a higher powered carrier signal, it can withstand a higher level of interference, even if the UE C/I and BS C/I ratios are very similar.

Method for BS to UE assessment

The method used for analysis of BS to UE interference is described in the following steps:

Step 1: Generate subscribers randomly in an urban region. The figure below illustrates random subscribers placed in the Strasbourg urban area. This large urban area was chosen for analysis since it is near to an international border, representing the most calling case for BS to UE interference. In this diagram, the BS in Germany are the interferers; UE in Strasbourg (shown as orange dots) are the victims.

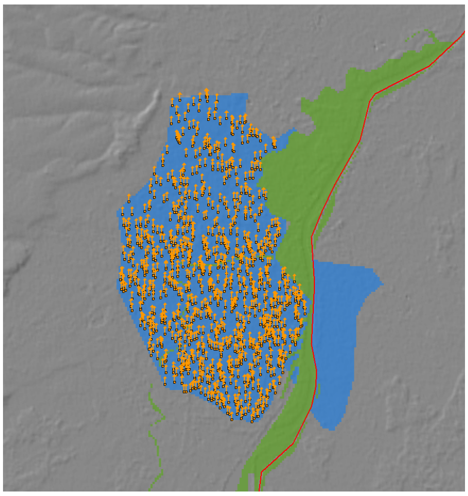


Figure 6.16: BS to UE Scenario: Strasbourg

Step 2: Calculate the distance between each subscriber and the serving cell. This is illustrated in Figure 6.17 below. Red dots indicate BS; black dots UE. The wanted signal path is shown as a black line.

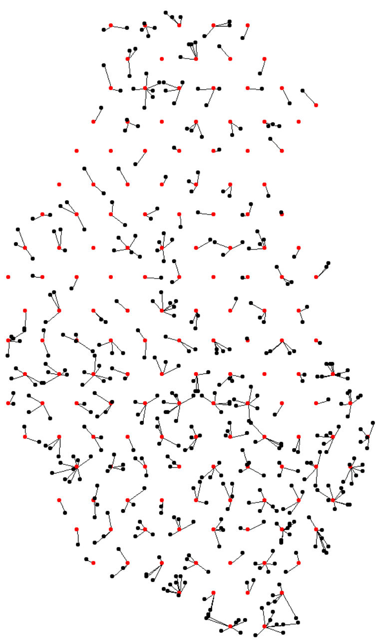


Figure 6.17: Calculating Distance between BS and MS [Source: Analysys Mason]

Step 3: Calculate the propagation loss using the Extended Hata Model for each link.

Step 4: Generate random log normal fade with 8 dB standard deviation (as per link budgets in Annex A & B).

Step 5: Using BS EiRP, propagation losses and fade, calculate the carrier signal received by the UE from the serving cell.

Step 6: As this area is very close to the border, we have assumed a constant level of interference equal to the interference threshold. We commenced with an interference field strength of 50dBuV/m/5MHz. We then calculate C/I values for each UE and from this the data throughput achieved.

Step 7: Calculate the percentage of UE where the interference margin is breached. Increase interference by 1dB and repeat steps 6 & 7 the breach approaches 10%. Note that as we are assuming no propagation losses for interference, actual breaches would be lower.

The analysis was repeated several times to ensure good randomisation of UE locations. Using this method, we found that a trigger level of **58dBuV/m/5MHz** was required to protect UE devices from BS interference. This value of interference gave a mean throughput of 2.8bps/Hz and a breach of 8.6%.

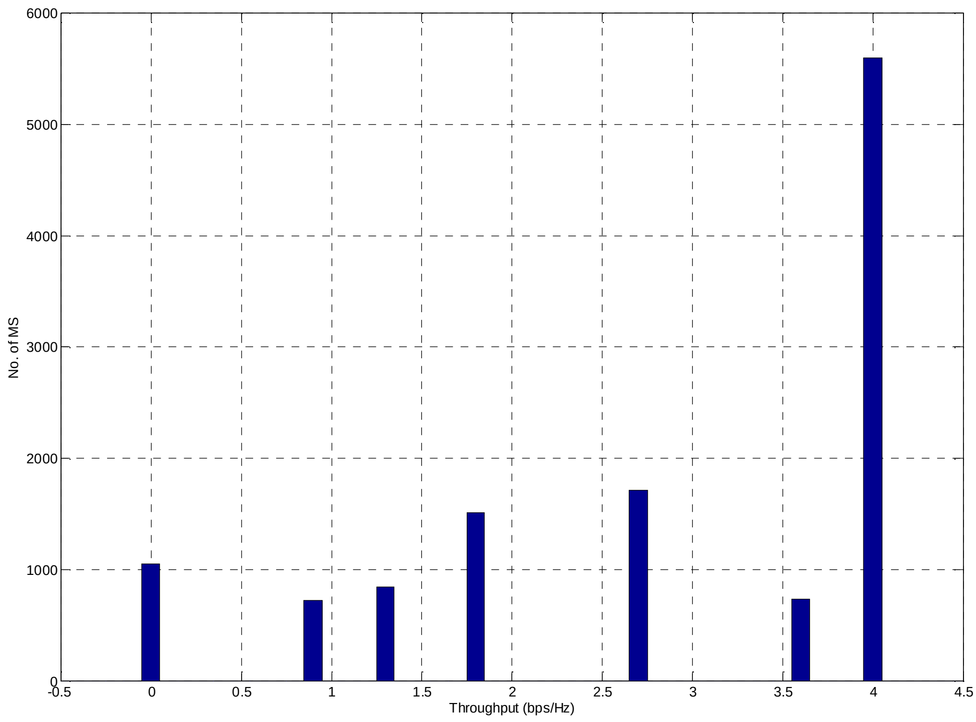


Figure 6.18: Throughput of WiMAX devices in Strasbourg in the presence of 58dBuV/m/5MHz interference

This confirms that in the case of uncoordinated networks the critical interference path is BS to BS, however if BS to BS interference is removed, by say TDD synchronisation, then a second trigger level of 58dBuV/m/5MHz is required to limit BS to UE interference.

Mitigation of BS to UE interference (WiMAX to WiMAX only)

BS to UE interference can be mitigated by the use of preferential sub-carriers. This could operate in a similar manor to the way preferential channels and preferential codes are used for international coordination of GSM and UMTS networks respectively. Each country in a border region is granted a set of preferred sub- carriers. These would be spread across the entire channel to ensure that the benefits of sub-channelization gain (due to variation in sub-carrier fading) are not reduced. There is however some loss in sub-channelization gain due to the reduced numbers channels available. Using this method, a higher trigger level can be set for preferred sub- carriers. We propose 65dBμV/m/5MHz, for consistency with the values used for preferential codes in ECC Recommendation 01 (01). This is high enough to allow a WiMAX operator to provide coverage right up to the border. Preferred sub-carriers removes the need for synchronisation and allows each operator to use the full channel on sites that will not breach the lower trigger threshold (30dBμV/m/5MHz), e.g. micro and pico cells plus macro cells some distance from the border.

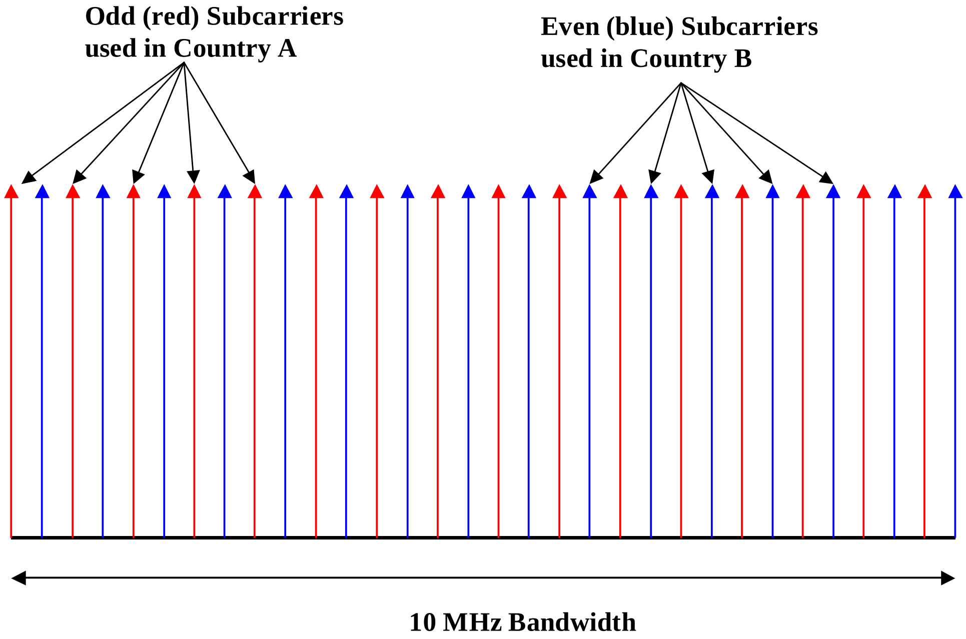


Figure 6.19: Illustration of preferential sub-carriers [Source: Analysis Mason]

7 Conclusions

Within this study, Analysys Mason has aimed to review the existing recommendations relating to cross border coordination of networks deployed in the 2.6 GHz band in Europe, as stated within ECC Recommendation (01)01.

In practice, we found that the interference that a victim base station needs to tolerate is the aggregation of all sources of interference, and that the number of interferers that make a **significant contribution** varies from scenario to scenario, but can be as few as one, two or three interferers; typically the closest interfering base stations to the test point.

Our detailed analysis of link budgets and propagation has led us to the conclusion that in order to protect victim TDD base stations, the **aggregated** interference predicted at test points 3m above the border should be no more than **30dBμV/m/5MHz**. This aggregated limit could be achieved by any number of combinations of interferers.

From the results of our second phase of analysis, conducted using ITU-R P.1812 with 50 metre terrain data, we have found that more practical (aggregated) international coordination thresholds 3m above ground level would be as follows:

- WiMAX TDD to WiMAX TDD: without synchronisation and without coordinated cross border fractional frequency re-use: **30dBμV/m/5MHz**
- WiMAX TDD to WiMAX TDD: with synchronisation: **58dBμV/m/5MHz**
- WiMAX TDD to WiMAX TDD: with coordinated cross border fractional frequency re-use: **65dBμV/m/5MHz** on preferred sub-carriers; **30dBμV/m/5MHz** on non-preferred carriers.
- UMTS HSPA to WiMAX TDD **30dBμV/m/5MHz.**
- WiMAX TDD to UMTS HSPA **14dBμV/m/5MHz.** (UMTS being more sensitive to interference)

These trigger levels provide a balance between protecting the victim systems whilst also avoiding requirements for a significant percentage of base stations in each network to be coordinated through the regulatory process.

In all cases the Bonn power sum of predicted interference is to be compared with the coordination trigger threshold at a series of 3m high test points located along the international border, spaced at 1km, using Rec. ITU-R P.1812 and an appropriate terrain database.

Note: 30dBμV/m/5MHz is equivalent to 33dBμV/m in a typical 10MHz WiMAX channel.

Figure 7.1 below summarises the results shown in detail in sections 6.1 and 6.2:

	Interferer		Victim
Senario	*Percentage of sites requiring coordination* [1]	*Trigger Level (dBuV/m/5MHz)*	*Percentage of Base stations Breached* [2]
UMTS to WiMAX Notebook (France to Switzerland)	32.7%	30	0.0%
WiMAX HH to UMTS (Germany to France)	40.5%	14	0.0%
WiMAX HH to WiMAX Notebook (Germany to Switzerland)	48.3%	30	3.6%
WiMAX Notebook to UMTS (Switzerland to France)	33.8%	14	1.4%
WiMAX Notebook to WiMAX Hand Held (Switzerland to Germany)	23.7%	30	5.0%
UMTS Notebook to WiMAX Hand Held (France to Germany)	47.7%	30	0.0%
UMTS to WiMAX Notebook (Belgium to Netherlands)	32.3%	30	-
WiMAX Notebook to UMTS (Netherlands to Belgium)	71.8%	14	-

Figure 7.1: Summary of results: impact of selected trigger level on Interferer and Victim networks.

1. Percentage of sites requiring coordination within 40km of the boarder, without mitigation applied.

2. Percentage of Base Stations which receive more than the permitted level of interference from the interfering sites that do not require coordination (i.e. those sites that together comply with the trigger level).

Annex A: HSPA Link Budget

Environment	*BS Height*	*UE Height*	*Unit*
urban	15	1.5	m
suburban	20	1.5	m
rural	30	1.5	m

Figure A.1: Base Station and User Equipment Antenna Heights

Downlink (Forward) HSDPA Link Budget	*Values*	*Units*
Frequency	2600	MHz
Channel Size	5	MHz
BS Max Tx Power	44	dBm
BS Tx Power (Balanced)	37.0	dBm
BS Antenna Gain	18	dBi
Cyclic Combining Gain (2 Antenna Elements)	3.01	dB
BS Cable Loss	2.4	dB
BS EIRP	55.6	dBm
Thermal Noise Density	-173.93	dBm/Hz
UE Noise Figure [6]	7.0	dB
UE Noise Density	-166.9	dBm/Hz
Chip rate	3840000	cps
UE Receiver Noise Power	-101.09	dBm
Downlink Data Rate	512.0	kbit/s
Spreading Factor	16	--
UE Processing Gain	12.0	dBm
Modulation and FEC	QPSK 1/2	--
UE SINR	1.9	dB
UE Sensitivity	-111.2	dBm
Load Factor	70.0%	%
UE Interference Margin	5.23	dB
Soft Handover Gain	0.0	dB
Fast Fade Margin (3km/h max)	2.0	dB
UE Antenna Gain	2.0	dBi
UE Body Loss	0.0	dB
UE Antenna Diversity Gain	3.01	dB
UE Required Signal Power	-109.0	dBm
Downlink Path Loss	164.6	dB
UE Interference Power	-97.4	dBm
C/I	-13.8	dB
Maximum interference at the UE antenna	-95.2	dBm
Maximum interference at the UE antenna	**50.31**	**dBuV/m**

Uplink (Reverse) HSUPA Link Budget	*Values*	*Units*
Frequency	2600	MHz
Channel Size	5	MHz
UE Max Tx Power	23	dBm
UE Antenna Gain	2.0	dBi
UE Body Loss	0.0	dB
Cyclic Combining Gain (2 Antenna Elements)	3.01	dB
UE EIRP	28.0	dBm
Thermal Noise Density	-173.93	dBm/Hz
BS Noise Figure	5	dB
BS Noise Density	-168.93	dBm/Hz
Chip rate	3840000	cps
BS Receiver Noise Power	-103.09	dBm
Uplink Data Rate	64.0	kbit/s
BS Processing Gain	17.8	dBm
Modulation and FEC	QPSK 1/2	--
BS SINR	1.9	dB
BS Sensitivity	-119.0	dBm
Load Factor	50.0%	%
BS Interference Margin	3.01	dB
Soft Handover Gain	2.0	dB
Fast Fade Margin (3km/h max)	2.0	dB
Mast Head amplifier gain	2.0	dB
BS Antenna Gain	18.0	dBi
BS Cable Loss	2.40	dB
BS Antenna Diversity Gain	3.01	dB
BS Required Signal Power	-136.6	dBm
BS Required Signal (FS)	8.93	dBuV/m
Uplink Path Loss	164.6	dB
BS Interference Power	-103.1	dBm
C/I	-15.9	dB
Maximum interference at the BS antenna	-120.7	dBm
Maximum interference at the BS antenna	**24.81**	**dBuV/m**

Figure A.2: UMTS HSPA Notebook PC Downlink and Uplink budgets Source: Analysys Mason

Margins and Planning Levels	*Values*	*Units*
Building Penetration Loss (BPL) Margin	10.00	dB
SD Lognormal Fading	8.00	dB
SD Building Penetration Loss	6.00	dB
Path Loss Exponent	3.52	--
Cell Edge Probability	75.0%	%
Cell Area Probability for Outdoor Coverage	89.9%	%
Cell Area Probability for Indoor Coverage	88.5%	%
Log Normal Slow Fade Margin (Outdoor)	5.40	dB
Log Normal Slow Fade Margin (Outdoor + BPL)	16.74	dB
Without Building Penetration Planning Level	-103.61	dBm
With Building Penetration Planning Level	-92.26	dBm
Without Building Penetration Planning Level	**41.89**	**dBuV/m**
With Building Penetration Planning Level	**53.23**	**dBuV/m**

Figure A.3: UMTS HSPA Notebook PC margins and Planning Levels for. Source: Analysys Mason

Annex B: WiMAX Link Budget

Downlink (Forward)	Handheld	Notebook	Units
Base Station Parameters			
BS Max Tx Power	44	44	dBm
Tx Power per Antenna Element (Balanced)	39.43	39.43	dBm
Number of Tx Antenna Elements	2	2	--
BS Antenna Gain	18	18	dBi
BS Cable loss	2.4	2.4	dB
Pilot Power Boosting Gain	0	0	dB
Cyclic Combining Gain	3.01	3.01	dB
BS EIRP	**58.04**	**58.04**	**dBm**
Base Permutation Zone	DL PUSC	DL PUSC	--
Number of Subcarriers	1024	1024	--
Number of Pilot Subcarriers	120	120	--
Number of Null Subcarriers	184	184	--
Total Occupied Subcarriers	840	840	--
Total Traffic Subcarriers	720	720	--
Power per Occupied Subcarriers	**28.80**	**28.80**	**dBm**
User Equipment Parameters	**Handheld**	**Notebook**	**Units**
Thermal Noise Density	-173.93	-173.93	dBm/Hz
Channel Bandwidth	10	10	MHz
Sampling Frequency	11.2	11.2	MHz
Sub-carrier Spacing	10.9375	10.9375	KHz
Composite Thermal Noise Power	-104.30	-104.30	dBm
Subcarrier Thermal Noise Power	-133.54	-133.54	dBm
Modulation and FEC	QPSK 1/2	QPSK 1/2	--
Required C/N	1.7	1.7	dB
UE Noise Figure	7	7	dB
Rx Sensitivity per Subcarrier	-124.84	-124.84	dBm
Composite Rx Sensitivity	**-95.60**	**-95.60**	**dBm**
UE Antenna Gain	0	2	dBi
UE Antenna Diversity Gain	3.01	3.01	dB
UE Body Loss	2	0	dB
Fast Fade Margin	2	2	dB
Interference Margin	2	2	dB
UE Required Signal Power	-92.61	-96.61	dBm
Downlink Path Loss	**150.65**	**154.65**	**dB**
UE Interference Power Allowance	-106.6	-106.6	dBm
C/I	11.0	11.0	dB
Maximum interference at the UE antenna	**-103.6**	**-107.6**	**dBm**
Maximum interference at the UE antenna	**41.86**	**37.86**	**dBuV/m**

Uplink (Downward)	Handheld	Notebook	Units
User Equipment Parameters			
Tx Power per Antenna Element	23	23	dBm
Number of Antenna Element	2	2	--
UE Antenna Gain	0	2	dBi
UE Body Loss	2	0	dB
Cyclic Combining Gain	3.01	3.01	dB
MS EIRP	**24.01029996**	**28.01**	**dBm**
Base Permutation Zone	UL PUSC	UL PUSC	--
Number of Subcarriers	1024	1024	--
Number of Pilot Subcarriers	280	280	--
Number of Null Subcarriers	184	184	--
Total Occupied Subcarriers	840	840	--
Total Traffic Subcarriers	560	560	--
Power per Occupied Subcarriers	**-5.23**	**-1.23**	**dBm**
Base Station Parameters	**Handheld**	**Notebook**	**Units**
Thermal Noise Density	-173.93	-173.93	dBm/Hz
Channel Bandwidth	10	10	MHz
Sampling Frequency	11.2	11.2	MHz
Sub-carrier Spacing	10.9375	10.9375	KHz
Composite Thermal Noise Power	-104.30	-104.30	dBm
Subcarrier Thermal Noise Power	-133.54	-133.54	dBm
Modulation and FEC	QPSK 1/2	QPSK 1/2	--
Required C/N	1.7	1.7	dB
BS Noise Figure	4	4	dB
Number of Subchannels	2	2	--
Subchannelisation Gain	12.43	12.43	dB
Rx Sensitivity per Subcarrier	-142.27	-142.27	dBm
Composite Rx Sensitivity	**-111.03**	**-111.03**	**dBm**
BS Antenna Gain	18	18	dBi
BS Antenna Diversity Gain	3.01	3.01	dB
BS Cable Loss	2.4	2.4	dB
Pilot Power Boosting Gain	0	0	dB
Fast Fade Margin	2	2	dB
Mast Head amplifier gain	2.0	2.0	dB
Interference Margin	3	3	dB
BS Required Signal (EI Received P)	-126.64	-126.64	dBm
BS Required Signal (FS)	18.86	18.86	**dBuV/m**
Uplink Path Loss	**150.65**	**154.65**	**dB**
BS Interference Power Allowance	-116.7	-116.7	dBm
C/I	5.7	5.7	dB
Maximum interference at the BS antenna	**-119.9**	**-119.9**	**dBm**
Maximum interference at the BS antenna	**25.57**	**25.57**	**dBuV/m**

Figure B.4: WiMAX Downlink and Uplink budgets Source: Analysys Mason

Margins and Planning Levels	*Handheld*	*Notebook*	*Units*
Building Penetration Loss (BPL) Mean	10.00	10.00	dB
SD Lognormal Fading	8.00	8.00	dB
SD Building Penetration Loss	6.00	6.00	dB
Path Loss Exponent	3.52	3.52	--
Cell Edge Probability	75.0%	75.0%	%
Cell Area Probability for Outdoor Coverage	89.9%	89.9%	%
Cell Area Probability for Indoor Coverage	88.5%	88.5%	%
Log Normal Slow Fade Margin (Outdoor)	5.40	5.40	dB
Log Normal Slow Fade Margin (Outdoor + BPL)	16.74	16.74	dB
Without Building Penetration Planning Level	-87.21	-91.21	dBm
With Building Penetration Planning Level	-75.86	-79.86	dBm
Without Building Penetration Planning Level	58.29	54.29	dBuV/m
With Building Penetration Planning Level	69.64	65.64	dBuV/m

Figure B.5: WiMAX Margins and Planning Levels. Source: Analysys Mason