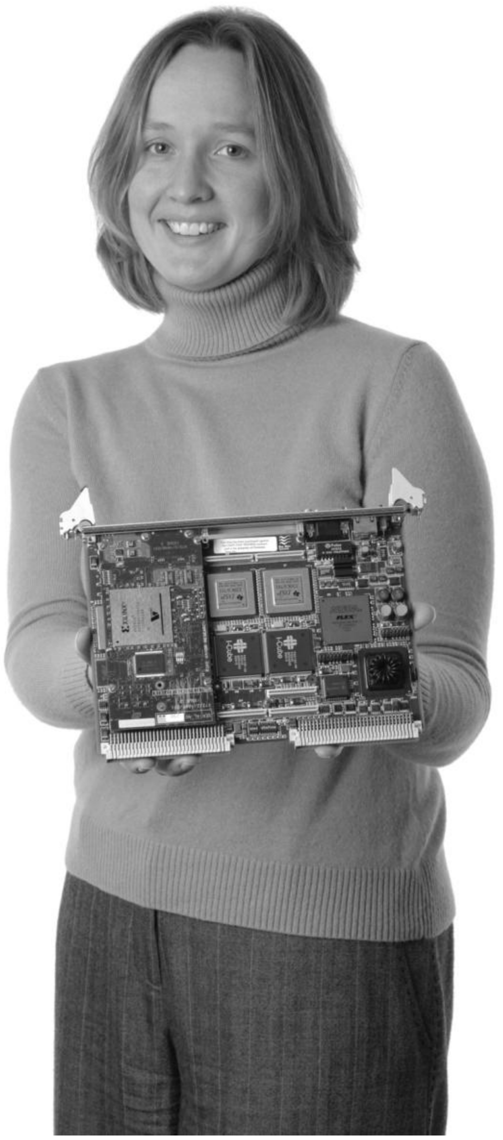
Practical Compatibility and Coexistence Measures Analysis

Produced for: WiMAX Forum

Against Order: 3484

Report No: 72/08/R/088/R
November 2008 – Issue 1.1



Roke Manor Research Ltd
Roke Manor, Romsey
Hampshire, SO51 0ZN, UK

T: +44 (0)1794 833000
F: +44 (0)1794 833433
info@roke.co.uk
www.roke.co.uk

Roke Manor Research Ltd
a Siemens company

Copy No. ………

This page intentionally left blank

Practical Compatibility and Coexistence Measures Analysis

Report No: 72/08/R/088/R
November 2008 – Issue 1.1
Produced for: WiMAX Forum
Against Order: 3484

Authors:
Dr Zoran Dobrosavljevic
Julian Trinder

Approved By
Ken Richardson …………………………………………….
Project Manager

Authorised By
Graham Williamson …………………………………………….
Business Sector Manager

Roke Manor Research Limited
Roke Manor, Romsey, Hampshire, SO51 0ZN, UK
Tel: +44 (0)1794 833000 Fax: +44 (0)1794 833433
Web: http://www.roke.co.uk Email: enquiries@roke.co.uk
Approved to BS EN ISO 9001 (incl. TickIT), Reg. No Q05609

DOCUMENT HISTORY

Issue no	Date	Comment
Draft A	17/06/2008	Draft issue of the document
Draft B	03/07/2008	Sections 2, 4, 5 and 6 added
Draft C	18/07/2008	Review comments incorporated
Issue 1	22/08/2008	Review comments incorporated
Issue 1.1	25/12/2008	Issue for publication

Practical Compatibility and Coexistence Measures Analysis

Report No: 72/08/R/088/R
November 2008 – Issue 1.1
Produced for: WiMAX Forum
Against Order: 3484

SUMMARY

Roke Manor Research Ltd (Roke) has been tasked by WiMAX Forum to develop interpretations of the results of the Draft ITU-R Report M.2113-1 [Ref 2] that deals with sharing issues in the 2.5 – 2.69 GHz band between the UMTS FDD and WiMAX TDD systems. The goal of the performed work has been to provide an interpretation that would help regulators to define clear coexistence and licensing agreements for their specific situations.

Conclusions regarding the coexistence issues and possible interference suppression measures, dependant on the values for the system parameters and scenarios adopted in [Ref 2] and in this analysis, are:

- Interference between the base stations in the two systems is the worst scenario, and the one where most of additional interference isolation has to be acquired;
- Coexistence in adjacent channels (i.e. without a guard band) is possible if special measures are applied. Specifically, one of the interfering channels has to be declared restricted, with limited base station transmit power, and antennas deployed below the rooftop level or indoors (micro and pico base stations);
- Co-location of the interfering macro BS requires sufficient isolation between them. This can be achieved through a combination of frequency separation (of one 5 MHz channel), RF channel filtering at the base stations and careful site engineering in order to achieve sufficient isolation between the antennas.
- When interfering base stations are not co-located, an element of spatial isolation between the interfering BS can be beneficial. Distances of around 250 m or more are expected to be sufficient in macro BS scenarios similar to the one analysed in ITU-R Report M.2113, [Ref 2].
- For non-collocated base stations that use multiple antennas, part of the required additional isolation can in many cases come from beamforming.

Roke Manor Research Limited
Roke Manor, Romsey, Hampshire, SO51 0ZN, UK
Tel: +44 (0)1794 833000 Fax: +44 (0)1794 833433
Web: http://www.roke.co.uk Email: enquiries@roke.co.uk
Approved to BS EN ISO 9001 (incl. TickIT), Reg. No Q05609

- Some MS-MS interference is unavoidable in all situations. However, this effect is of a transient nature, can potentially affect a small number of users, and is to some extent alleviated by the measures that need to be applied to enable coexistence between the base stations.

- Coordination between the operators that might be involved in mutual interference is advisable, as they are best placed to coordinate their frequency plans and actions in order to mitigate the problems.

- Severity of coexistence problems depends on frequency: coexistence is easier to solve in the 3.5 GHz band, while in the UHF band becomes extremely challenging. This is mainly due to the dependence of path loss on frequency, and can be at least partially solved with the use of appropriate coexistence measures, such as high quality RF channel filtering.

The report also gives an overview of the current standardisation activities in Europe relevant to the subject of FDD – TDD coexistence.

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

This report describes work performed by Roke Manor Research Ltd (Roke) for the WiMAX Forum in developing interpretations of the results of the Draft ITU-R Report M.2113-1 [Ref 2] specific to WiMAX. The goal of the proposed work is to provide an interpretation that will help regulators to define clear coexistence and licensing agreements for their specific situations. The output of the work is a Technical Report to be published on the WiMAX Forum Regulatory Portal website, formulated to augment the information already available at the Portal, and a separate Working Paper containing our key recommendations.

The problem of coexistence between the radio systems that either share the frequency band or operate in adjacent bands is not new; all radio systems face coexistence problems to a certain extent, and need appropriate measures to address them. However, a presence of TDD and FDD broadband wireless access systems providing mobile services to users can potentially pose some unique challenges to coexistence that need to be addressed.

This report details the work carried out by Roke Manor Research in addressing the issues of WiMAX TDD and UMTS FDD coexistence, in response to the WiMAX Forum RFQ [Ref 25]. The work is broken down into the following six sections:

- **Section 1: Introduction.** This section.
- **Section 2: Impact of co-existence environment.** The objective of this section is to interpret the results of the ITU-R sharing studies between WiMAX and other IMT-2000 systems given in [Ref 2] and [Ref 26], in terms that address the issues of interest to regulators. The interpretation is intended to augment the information already available on WiMAX Forum Information Portal.
- **Section 3: Mitigation techniques.** This section investigates mitigation techniques that could potentially alleviate some of the co- existence interference scenarios identified in Section 2. Efficiency of these techniques are given in qualitative terms.
- **Section 4: Sensitivity analysis.** This section focuses on the sensitivity analysis of the practical improvements gained when using the proposed mitigation techniques identified in Section 3. Taking into account the variation of results given in [Ref 5]. The sensitivity is expressed in qualitative terms, indicating robustness of the described mitigation techniques.
- **Section 5: Standardization and regulatory activities in Europe.** The objective of this section is to produce a brief overview of the current state of standardisation activities in Europe relevant to the questions of coexistence between WiMAX and other IMT-2000 systems. The work is limited to ETSI standardization activities and ECC work in Project Team 1 (PT1) and in relation to WAPECS.
- **Section 6: Impact of frequency.** The objective of this work package is to produce a qualitative assessment of the extent to which conclusions on mitigation techniques (WP2 and WP3) are relevant to other frequency bands. The work is limited to the 3.5 GHz band and the upper part of the UHF band that will be released with a switchover to digital TV broadcasting (the "digital dividend").

The report also contains a list of references and acronyms. A discussion of the use of block edge masks as means of facilitating the coexistence between the TDD and FDD systems is given in the Appendix.

2 IMPACT OF CO-EXISTENCE ENVIRONMENT

2.1 INTRODUCTION

The 2500-2690 MHz band (2.5 GHz band in the following text) is one of several bands identified by the International Telecommunication Union (ITU) for possible use for systems based on International Mobile Telecommunications (IMT) technologies. The two main candidate technologies for this band are UMTS (including the Long Term Evolution, LTE), and WiMAX (IEEE 802.16e). These, are, however, based on different duplex techniques: UMTS predominantly uses frequency division duplex (FDD), while WiMAX is based on time division duplex (TDD). This brings forward the important question of coexistence.

Coexistence of TDD and FDD – based mobile cellular networks in the same frequency band and in the same geographical area presents a considerable challenge due to the high probability of mutual interference and the resultant performance loss the coexisting systems can suffer. However, when the question of TDD – FDD coexistence was addressed before, e.g. in [Ref 1] and elsewhere, it was mainly in relation to UMTS FDD coexisting with UMTS TDD in the 2 GHz band. Recently the focus of attention has shifted to the coexistence of UMTS FDD with WiMAX TDD, as shown e.g. in [Ref 2], [Ref 3].

The discussions in this section are based mainly on the results of the ITU work given in the Draft ITU-R Report M.2113-1, [Ref 2]. The report gives an exceedingly thorough examination of the coexistence issues between UMTS FDD and WiMAX TDD sharing a common geographical service area (the document also looks into the MMDS systems, but this is not the subject of this study). The report [Ref 2] is, however, quite verbose and requires considerable effort on the part of the reader to comprehend fully.

It should be noted that the Report M.2113-1 has addressed the fixed and nomadic WiMAX systems. As the issue of coexistence in mobile scenarios is a subject of ongoing studies at the time of writing of this report, the underlying assumption adopted in this section is that the results for nomadic systems given in [Ref 2] are sufficiently representative to be used in coexistence analysis for mobile TDD systems as well.

A major goal of the work performed in this section is to impart a clear understanding of the mechanisms involved in the coexistence issue. It is important for the system planner to have a clear grasp of the issues and effects, rather than just having tables of figures to work with. Bringing clarity to the complex issue of coexistence is our main objective.

The approach taken in this study follows the traditional "compatibility and sharing analysis" method, as described in Draft CEPT Report 019 [Ref 4] Section 4.4.1, Model 1. This approach is based on the regulated minimum technical performance parameters which all equipment suppliers are obliged to meet. Adopting the minimum technical standards for the study can lead to unduly pessimistic isolation margins. Therefore, the ITU Report [Ref 2] has followed the analytical results with results of statistical analysis that leads to the modeled system performance averaged over the population of users.

Our study mandate as outlined in [Ref 5] constrains us to use the equipment parameters defined in [Ref 2], effectively isolating our study from the vicissitudes of the market.

2.2 2.5 GHz Band Usage

Selection of potential TDD - FDD interference scenarios in the 2.5 GHz band is dependant on how the band is divided into TDD and FDD blocks. The initial approach to the division of the 2.5 GHz band is given in the Decision (05)05 [Ref 6] of the Electronics Communication Committee (ECC). This document divides the 2.5 GHz band into two FDD blocks, an uplink and a downlink, each 70 MHz wide, with 50 MHz of spacing between them that can be used for TDD systems. The ECC Decision (05)05 also defines a channel arrangement across the band, based on 5 MHz channels.

TDD and FDD blocks, channels, interference sources and victims for both FDD – TDD and TDD – FDD boundaries are illustrated in Figure 1.

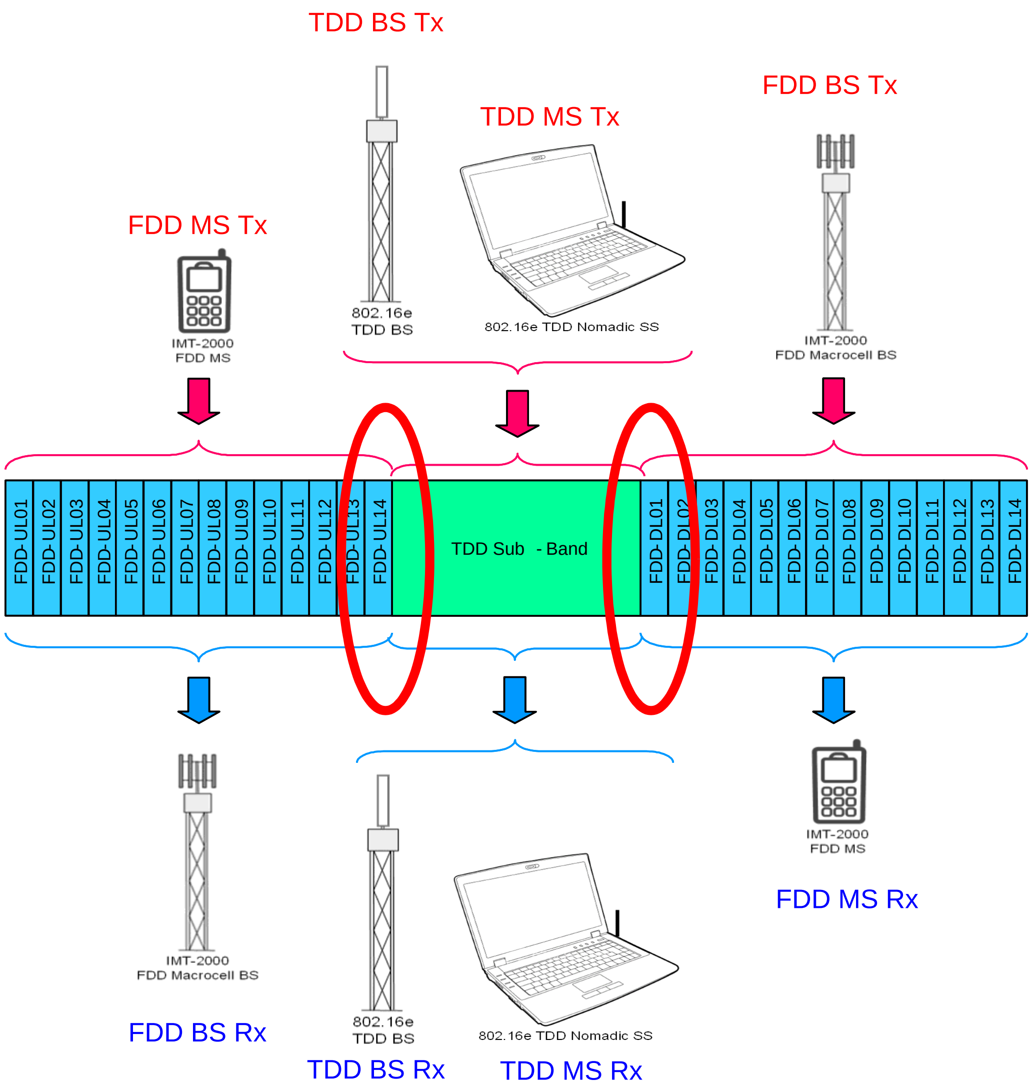


Figure 1 – TDD – FDD block boundaries and interfering equipment

More recently, the Decision of the European Commission (EC) 2008/477/EC [Ref 27] has called for neutrality in regard to technology that can be deployed in the 2.5 GHz band, and for flexibility in dividing the spectrum between the TDD and FDD technologies. One possible way this flexibility can be achieved is shown in Figure 2.

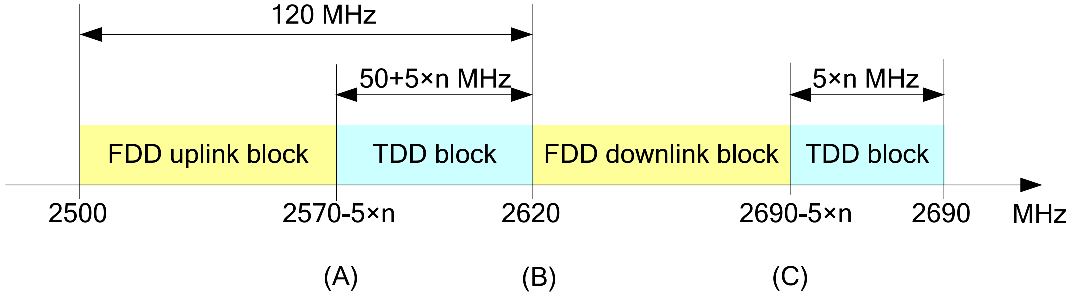


Figure 2 – One possible division of the 2.5 GHz band in to TDD and FDD blocks

As shown in this figure, it is expected that the individual national regulators will divide the 190 MHz of spectrum between 2500 MHz and 2690 MHz into up to four adjacent frequency blocks. In each block, only FDD or TDD operation will be permitted, at least initially. The FDD uplink block will begin at 2500 MHz, while the FDD downlink block will begin at 2620 MHz. Spacing between the paired FDD channels (uplink-downlink) will be 120 MHz.

The block of frequencies between the FDD uplink and downlink is expected to be dedicated to the TDD systems. This block will be 50 +5n MHz wide, where "n" is the value that will control the division of the 2.5 GHz band between the TDD and FDD technologies. Where "n" can be 0, 1, 2…, reflecting the 5 MHz channel plan. The value of "n" > 0 will also result in another, smaller TDD block at the upper edge of the 2.5 GHz band. This block is needed in order to preserve the 120 MHz uplink – downlink duplex spacing in the FDD.

The exact frequencies of the boundaries (A) and (C) between FDD and TDD frequency blocks in Figure 2 are therefore not fixed, and may differ from one country to another. Moreover, the split between the FDD and TDD spectrum may potentially change over time, if the market preference for one of the candidate technologies over another is different from the initial assumption made by the regulator.

It can be seen from Figure 2 that, due to the proposed 2.5 GHz frequency allocation plan up to three boundaries can exist between the FDD and TDD blocks. These boundaries are:

- (A): a boundary between the FDD uplink block and TDD block;
- (B): a boundary between the TDD block and FDD downlink block; and
- (C): a boundary between the FDD downlink block and TDD block.

At each boundary there can potentially be channels at either side of the boundary that belong to two different operators, wanting to provide broadband wireless access (BWA) to the same population of mobile users in the same geographical area. Each operator will deploy a cellular network based on the duplex technology prescribed by channel plan, so one could deploy a WiMAX TDD network and the other could deploy a UMTS FDD (or its evolved variant, the Long Term Evolution, LTE) network. Such a scenario can easily lead to active transmitters and receivers of the two disparate systems being close in both frequency and space, causing interference to each other, and leading to coexistence issues. The severity of these coexistence issues depends on the:

- Scenario in question: is the interference happening between the two BSs, between the two MSs, or between the BS and MS?

- Frequency separation: are the two interfering systems at the TDD – FDD boundary adjacent (the 1st channel issue) or is there at least a 5 MHz gap between them (the 2nd adjacent channel and beyond)?

- Spatial separation: are the interference source and victim collocated, or separated in space?

The effects of mutual interference in TDD - FDD coexistence scenarios are often asymmetric; in other words, one system will suffer more from mutual interference than the other. For example, an FDD MS operating at the boundary A in Figure 2 can potentially strongly interfere with a nearby TDD BS's reception, thus affecting all TDD users in that sector. At the same time, other FDD users may be quite unaffected by the TDD BS's interference, assuming they are sufficiently far from the TDD BS. This means that the operators of the two systems may not feel the same urgency to implement interference mitigation measures, and that the regulator may need to impose some measures (or incentives) in order to set up fair conditions for all operators.

The question of mutual interference is not limited to systems at the TDD – FDD boundary. Similar coexistence problems are faced when operating co-existing unsynchronised TDD systems. Co-existing FDD systems can also cause mutual interference through the so-called near-far problem. These issues, however, have been present in the cellular networks for some time.

2.3 Equipment Characteristics

The main radio equipments that participate in various coexistence scenarios are:

- UMTS FDD BS (Macro/Micro/Picocell)
- UMTS FDD MS
- WiMAX (IEEE 802.16e) TDD BS
- WiMAX TDD Fixed SS
- WiMAX TDD Nomadic SS

The following tables, from [Ref 2], show the values of important parameters that affect the TDD – FDD coexistence feasibility.

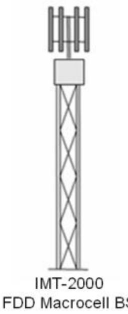
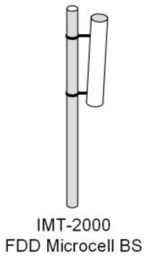
UMTS FDD CDMA-DS				
	Macrocell BS	**Microcell BS**	**Picocell BS**	**MS**
Graphic				
Max Tx power	+43 dBm	+38 dBm	+24 dBm	+21 dBm
Antenna gain	17 dBi	5 dBi	0 dBi	0 dBi
Max Tx EIRP	+60 dBm	+43 dBm	+24 dBm	+21 dBm
Antenna height	30 m	6 m	1.5 m	1.5 m
ACLR1 @ 5MHz	45 dB			33 dB
ACLR2 @ 10MHz	50 dB			43 dB
ACS1 @ 5MHz	46 dB			33 dB
ACS2 @ 10MHz	58 dB			43 dB
Rx NF	5 dB			9 dB
Rx noise BW	3.84 MHz			

Table 1 – UMTS FDD Equipment

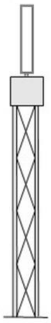
WiMAX TDD			
	BS	**Fixed SS**	**Nomadic SS**
Graphic			
Max Tx power	+36 dBm	+24 dBm	+20 dBm
Antenna gain	18 dBi	8 dBi	3 dBi
Max Tx EIRP	+54 dBm	+ 32 dBm	+23 dBm
Antenna height	30 m	4 m	1.5 m
ACLR1 @ 5MHz	53.5 dB	37 dB	33 dB
ACLR2 @ 10MHz	66 dB	51 dB	
ACS1 @ 5MHz	70 dB	40 dB	
ACS2 @ 10MHz	70 dB	59 dB	
Rx NF	3 dB	5 dB	
Rx noise BW	4.5 MHz		

Table 2 – WiMAX TDD Equipment

2.4 INTERFERENCE SCENARIOS

In TDD – FDD coexistence investigation, there are four interference scenarios to be considered. These scenarios depend on whether a base station (BS) or mobile station (MS) is a source or victim of interference, and are illustrated in Figure 3.

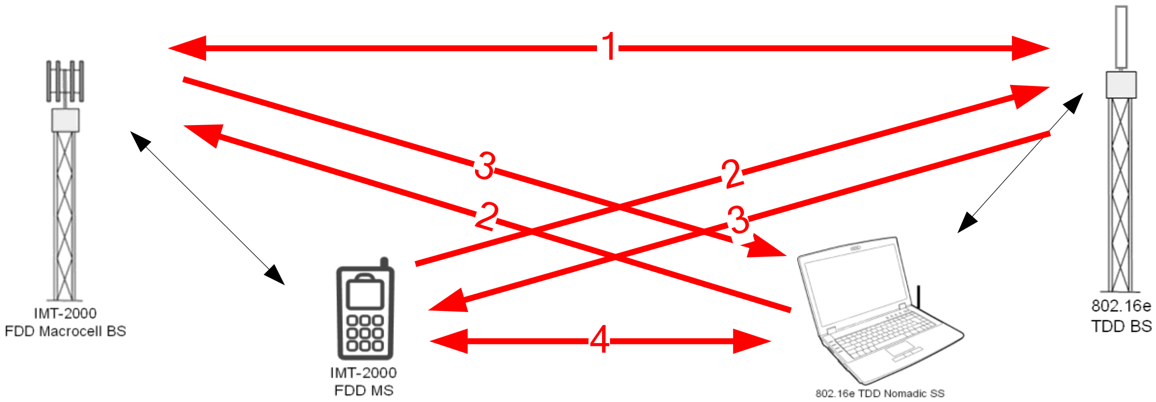


Figure 3 – Four key interference scenarios

The four interference scenarios are:

1. BS is both a source and a victim of interference (BS –> BS)
2. MS is a source, BS is a victim (MS -> BS);
3. BS is a source, MS is a victim (BS -> MS); and
4. MS is both a source and a victim (MS -> MS)

These four interference scenarios are ordered roughly by their criticality, according to the results given in [Ref 2]. The most critical scenario is BS -> BS interference, as it is relatively static (i.e. persists for a long period of time) and affects a large number of users, potentially all the users of both systems that interfere with each other. The MS -> BS interference is seen as less critical, because it is more transient (i.e. can appear only when an active interfering MS is close to a victim BS), but it can still potentially affect a large number of users the victim BS is serving. In the BS -> MS interference scenario, the population of affected users is relatively small (only the users close to the offending BS), but the effect is persistent in terms of spatial location (a "blind zone" may exist around an interfering BS). Finally, in the MS -> MS scenario, the number of users affected is small (potentially, only two), the effects are local and transient, and there is at least one available straightforward solution to mutual interference: the interfering users have to move away from each other.

For each of the four interfering scenarios, there are two possible directions of interference:

- UMTS FDD is the source of interference, WiMAX TDD is the victim (FDD -> TDD); and
- WiMAX is the source, UMTS is the victim (TDD -> FDD).

As shown in [Ref 2], the two radio access technologies may have different levels of vulnerability in mutual interference scenarios, caused e.g. by the different adjacent channel selectivity (ACS). The impact of inter-system interference can also be expressed differently in UMTS and WiMAX systems: it may cause capacity loss in UMTS and modulation efficiency loss and increased outage rate in WiMAX.

Finally, different BS deployment scenarios also have an influence in inter-system coexistence scenarios, mainly due to the different transmit powers, antenna gains, deployment scenarios and associated path losses associated with them. The three BS deployment scenarios discussed in [Ref 2] are:

- Macro BS, in rural / suburban environments, with antenna masts above the surrounding buildings and hence generally free space propagation losses to interference victim receivers;

- Micro BS, typical for dense urban deployments, with antennas below rooftops, with lower transmit powers and additional shadowing loss towards victim receivers; and

- Pico BS, deployed indoors, with lowest transmit powers and additional wall penetration losses in most cases.

2.5 Key Coexistence Factors

The issue of coexistence of two dissimilar (FDD and TDD) systems can be seen as dependant on a set of key factors that influence the mutual interference in different scenarios. These factors are illustrated in the following Figure.

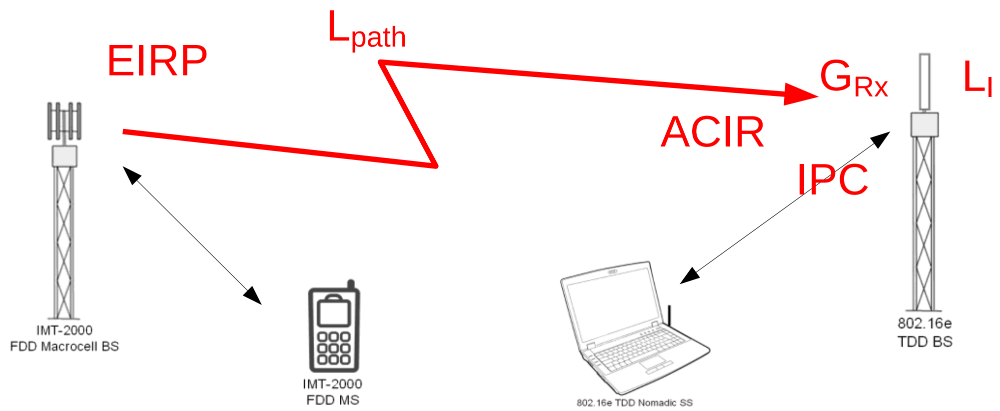


Figure 4 – Key factors affecting inter-system interference

The key factors are:

- Transmit Effective Isotropic Radiated Power (EIRP);

- Path loss (L_{path});

- Receive antenna gain (G_{Rx});

- Adjacent Channel Interference Ratio (ACIR);

- Additional interference suppression (L_I); and
- Interference Protection Criteria (IPC)

The following inequality containing the above factors has to be satisfied, if the two interfering systems are to successfully coexist:

$$EIRP - L_{path} + G_{Rx} - ACIR - L_I \leq IPC \quad (dBm) \tag{1}$$

The interpretation of the individual parameters is given in the following text.

2.5.1 EIRP

The EIRP is a sum (in decibels) of the transmit power and transmitter antenna gain towards the victim receiver. Maximal EIRP is often limited by the appropriate standards for different classes of transmit equipment that participate in the interference scenarios. The possible measures to reduce the interfering EIRP are to

- Reduce the Tx power;
- Reduce the Tx antenna gain towards the victim receiver's antenna.

Often, however, these measures conflict with the coverage requirement; i.e. reduction of the transmit power can lead to a reduction of cell range.

2.5.2 Path Loss

This is perhaps the most complex issue for coexistence studies, reflecting the diversity of the environment. This is an area where considerable simplification can be made at the expense of some loss of accuracy. However, this is felt necessary due to the heavy burden of detailed radio propagation planning in any given deployment scenario.

From ITU-R Report [Ref 2], the free-space pathloss at 2.6 GHz is quoted as

$L_{freespace} = 40.7 + 20.\log_{10}(d)$ in dB, where d is in metres, corresponding to

$L_{freespace} = 20.\log_{10}\left(\frac{4\pi.d}{\lambda}\right)$ in dB.

A more comprehensive model is provided in ITU-R Rec. P-452-12 [Ref 28], Equation 9.

For the statistical simulations of [Ref 2], a simple dual-slope model was used for LOS propagation between Basestations at 2.6 GHz:

$$L_{BS-BS} = \begin{cases} 40.7 + 20.\log_{10}(d), & d < d_{break} \\ 40.7 - 20.\log_{10}(d_{break}) + 40.\log_{10}(d), & d > d_{break} \end{cases} \tag{2}$$

where $d_{break} = \frac{4.h_{tx}.h_{rx}}{\lambda}$, units in meters.

A more general form of the dual-slope model is …

$$L_{BS-BS} = \begin{cases} 20.\log_{10}(4\pi.d/\lambda), & d < d_{break} \\ 40.\log_{10}(4\pi.d/\lambda) - 20.\log_{10}(4\pi.d_{break}/\lambda), & d > d_{break} \end{cases} \quad (3)$$

where $d_{break}/\lambda = \frac{4.h_{tx}.h_{rx}}{\lambda^2}$

In an example for UMTS BS to WiMAX BS interference scenario,

$h_{tx} = h_{rx} = 30m$, $\lambda = 0.1153m$, $d_{break} = 31.2km$

The free-space propagation loss at this break range is 130.6dB.

For this study, the ITU-R Rec. P.452-12 semi-empirical LOS model is considered to be too complex for rough coexistence planning.

2.5.3 Receive Antenna Gain

This parameter is the antenna gain of the receiver that is the victim of interference, expressed in decibels, towards the source of interference.

Since what is important is the gain in the direction of the interference source, interference suppression measures rely on reduction of the victim antenna gain in that direction, e.g. by increasing antenna down tilt, using site engineering to position the antenna so a null in the radiation pattern will point towards the interference source, etc.

2.5.4 Adjacent Channel Interference Ratio (ACIR)

The ACIR is the main factor that affects the ability of two systems to co-exist without causing excess interference to each other. For two coexisting systems, the ACIR is a combination of

- Adjacent channel selectivity (ACS) of the victim receiver, that describes how good (or selective) the victim receiver is, and
- Adjacent channel leakage ratio (ACLR) of the offending transmitter, describing how good (band-limited) the interfering transmitter is.

Possible measures to improve ACIR are:

- Improve ACS, using an additional Rx filter;
- Improve ACLR, using a more linear power amplifier, using more amplifier back-off, installing an additional Tx filter, etc.
- Increase the guard band width between the interfering and the victim system;

Transmit ACLR and receiver ACS linear power ratios are combined to form ACIR:

$$ACIR = \frac{1}{\left(\frac{1}{ACLR}\right)+\left(\frac{1}{ACS}\right)} = \frac{ACLR.ACS}{ACLR+ACS} \qquad (4)$$

Illustration of the relationship between the ACLR, ACS and ACIR is shown in Figure 5 for a situation where a WiMAX BS is interfering with a UMTS BS.

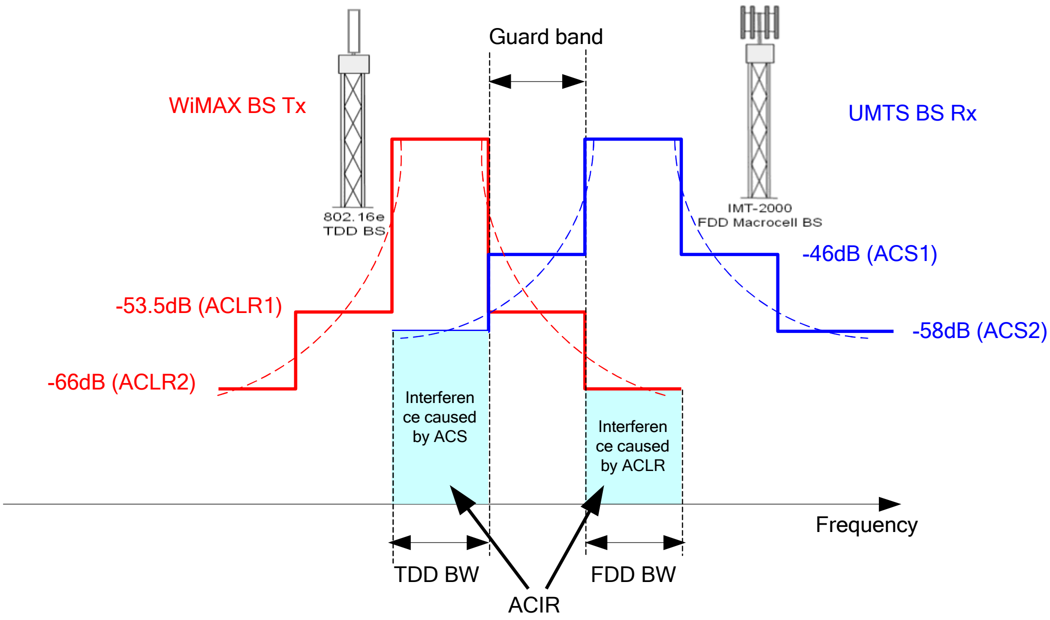


Figure 5 – Impact of ACLR and ACS on inter-system interference

Note that where there is a large difference between ACLR and ACS, the weaker of the two tends to dominate. In most important BS – BS interference scenarios, it is usually ACLR that dominates over ACS, so coexistence enabling measures can primarily be found in the area of ACLR improvement. This is discussed in more detail in Section 3.

2.5.5 Interference Protection Criteria (IPC)

Interference protection criteria (IPC) defines how much interference is allowed to be present at the victim receiver input. It is generally accepted that interference is acceptable if it does not degrade the victim system performance below a certain threshold, e.g. 5% of capacity loss, or 3 dB of E_b/N_0 degradation. The most common measure is 1 dB increase in the victim receiver noise floor, caused by interference that is 6 dB below the thermal noise. This is defined as IPC_6 and calculated as

$$IPC_6 = 10.\log_{10}\left(k.T_{sys}.BW\right) + NF - 6 \quad (dBm) \qquad (5)$$

Where BW is the receiver nose bandwidth, NF is the noise figure, and kT_{sys} is -174 dBm/Hz. Other often used values are IPC_{10}, where interference is 10 dB below the noise floor and increase in victim receiver noise is close to 0.5 dB. Available measures to increase IPC are, among others:

- Accept higher interference (more degradation), or
- Suppress interference in the receiver (e.g. adaptive interference cancellation).

2.6 EXAMPLES OF INTER-SYSTEM INTERFERENCE SCENARIOS

Some examples of different interference scenarios, cases are illustrated in the following sub sections. The examples also give the calculated isolation (includes path loss and other loss factors) for the interference protection criteria of 10 dB, IPC_{10}.

2.6.1 FDD MACRO BS -> TDD MAXRO BS SCENARIO

In this example, we consider a WiMAX TDD BS receiver operating in 2610-2615 MHz, and an UMTS FDD Macrocell BS transmitter operating in 2620-2625 MHz (DL01), on a carrier frequency of 2622.5 MHz. The two systems are separated by a 5 MHz guard band, as illustrated below.

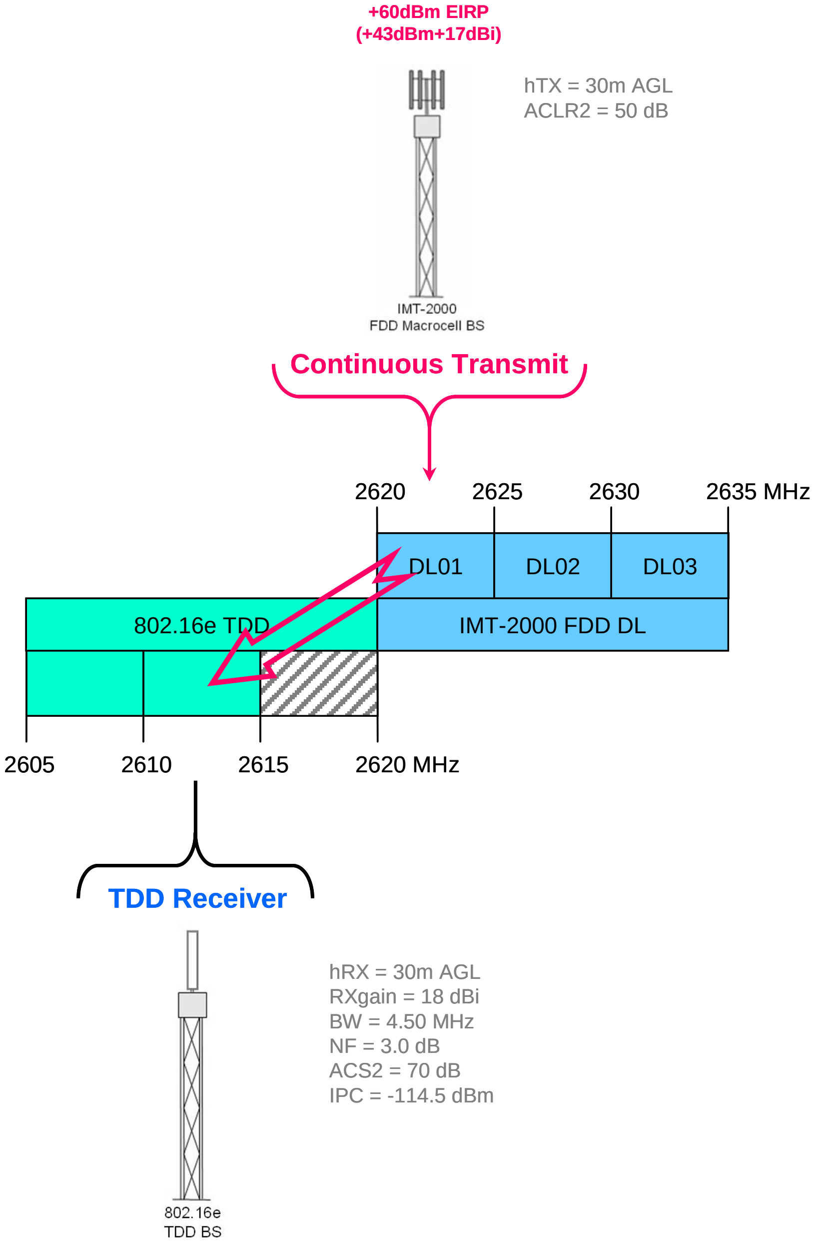


Figure 6 – WiMAX TDD BS as victim (TX = FDD Macrocell BS)

The interference level plan for this scenario is given in Figure 7.

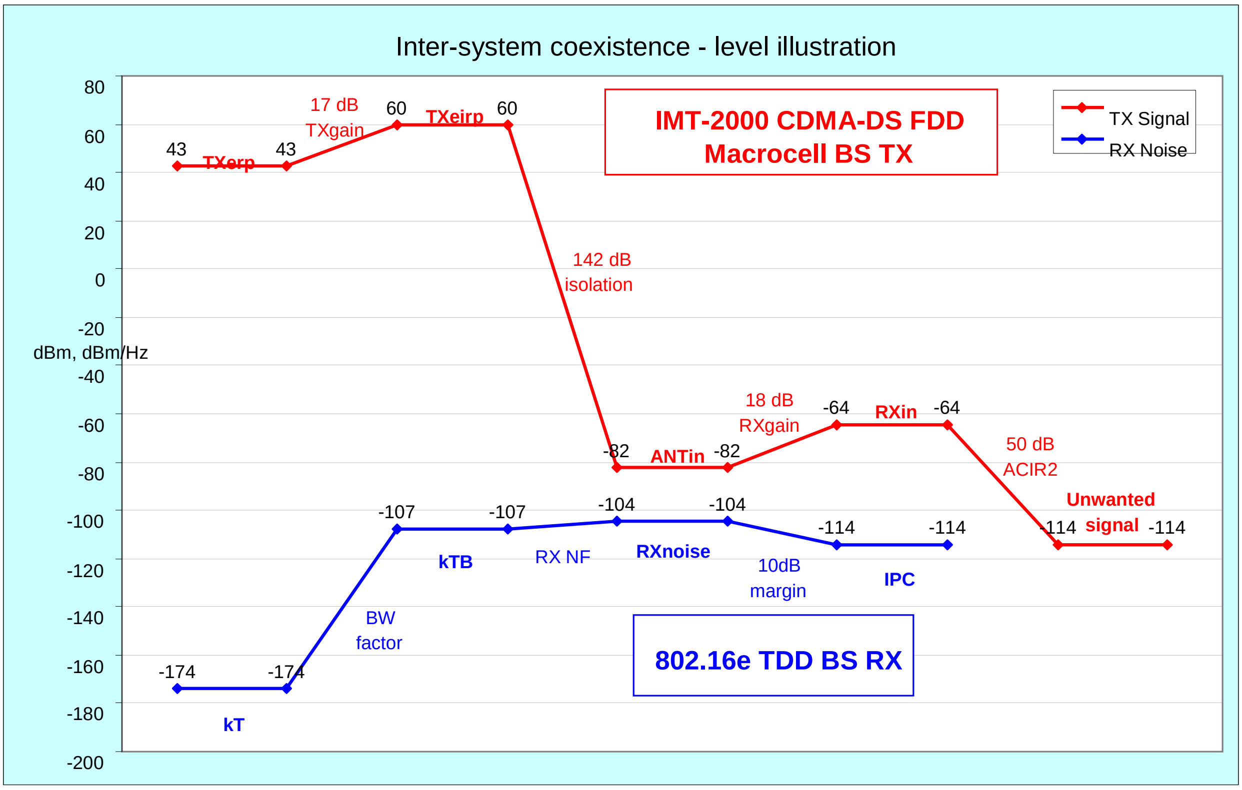


Figure 7 – Levels: TDD BS as victim (TX = FDD Macrocell BS)

In this scenario, we require isolation of 142 dB on the UMTS FDD transmit signal in order to meet the interference protection criteria (IPC) of the WiMAX TDD BS receiver of 10 dB below the noise floor. If that amount of isolation is to be achieved through path loss only on channel DL01 (2622.5 MHz), a radio path loss of 142 dB would require a separation of 61.7 km, which is well beyond the dual-slope break-range of 31.5 km based on TX and RX antenna heights.

Clearly, in this case the isolation requirement can be reduced by improvements to the UMTS FDD Macrocell BS TX ACLR2 (50 dB), e.g. by using additional transmit filtering, by improving PA linearity, by careful antenna beamforming, or by a combination of methods.

2.6.2 UMTS MS AS VICTIM (TDD MACRO BS -> FDD MS)

In this example, we consider a UMTS FDD MS receiver on channel DL01, and a WiMAX TDD BS transmitter operating in 2610-2615 MHz, on a carrier frequency of 2612.5 MHz. The two systems are separated by a 5 MHz guard band, as illustrated below.

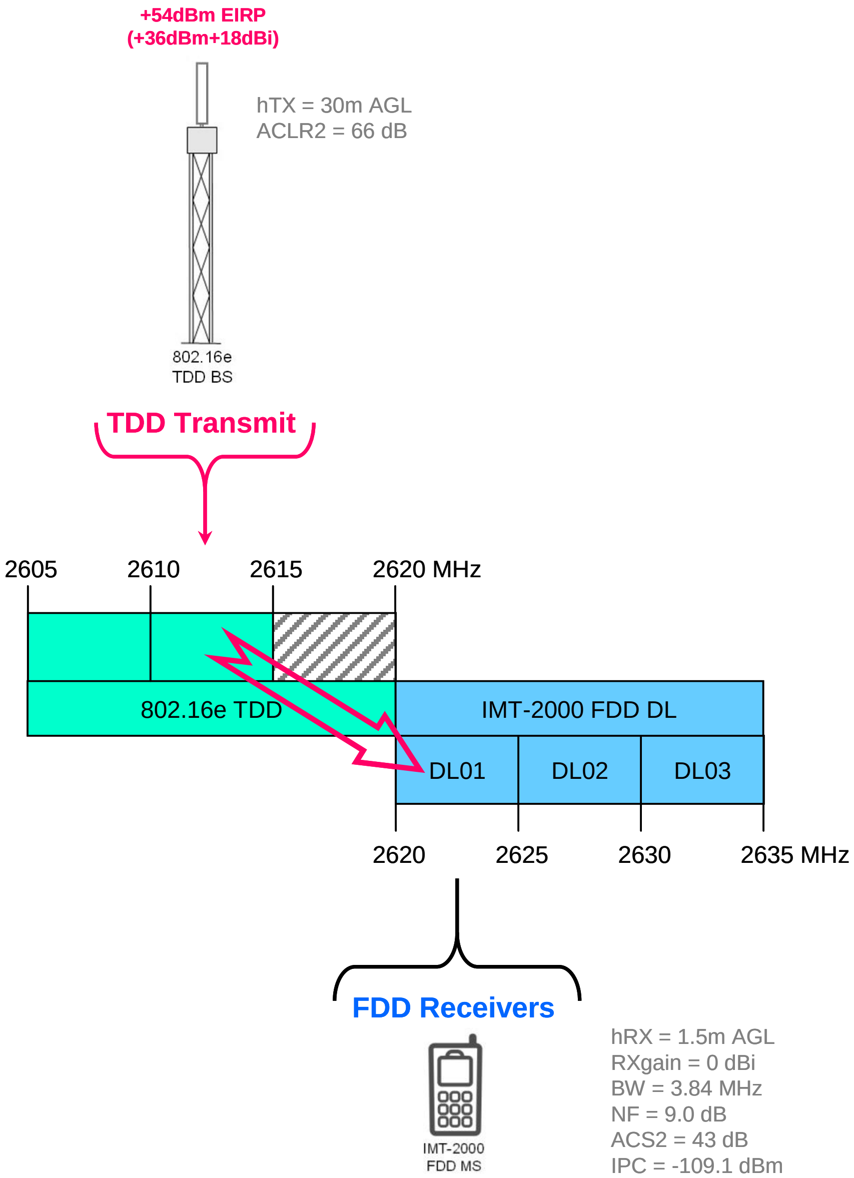


Figure 8 – UMTS FDD MS as victim (TX = TDD BS)

The interference level plan for this scenario is given in Figure 9.

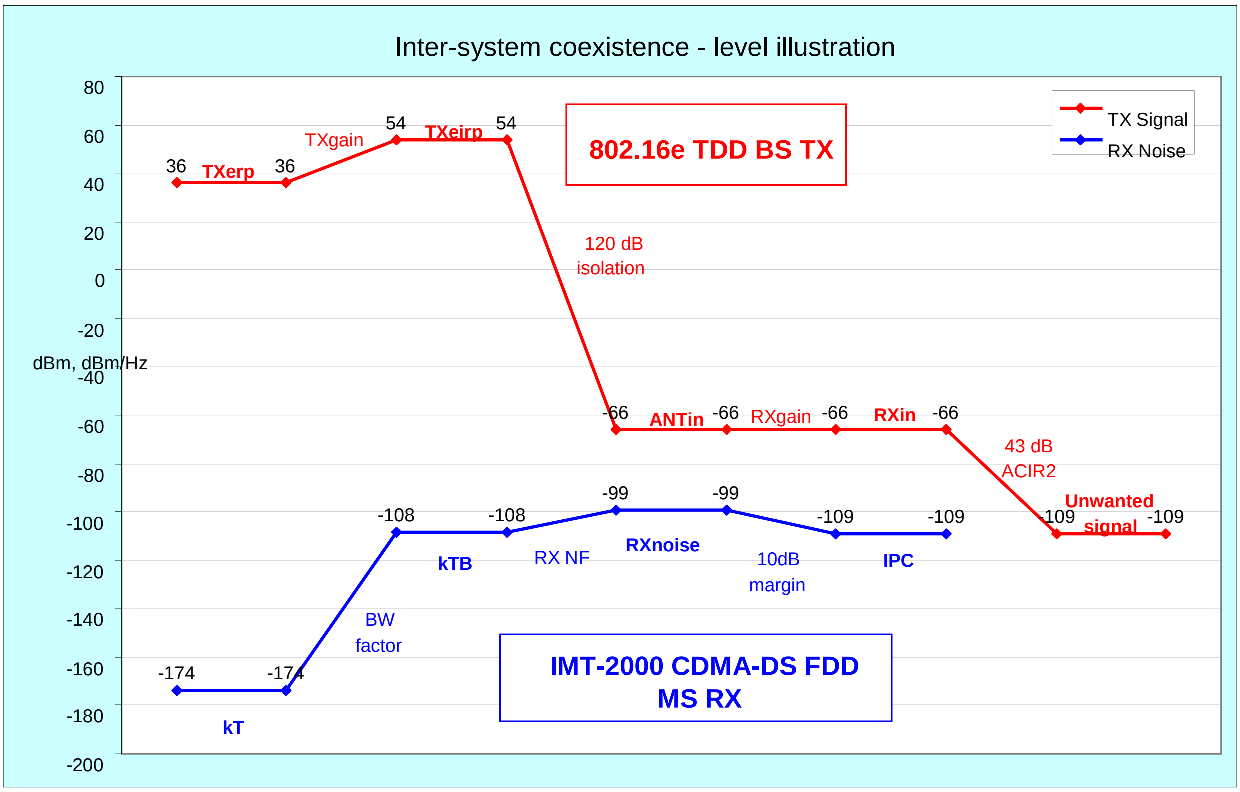


Figure 9 – Levels: FDD MS as victim (TX = TDD BS)

In the above illustration, the isolation was adjusted to 120 dB, in order to meet the receiver IPC limit (-109 dBm). At the transmit carrier frequency of 2612.5 MHz, this loss represents 3.83 km range between the TDD Basestation and the FDD MS. Since this range is greater than the dual-slope break-range of 1.57 km derived from the antenna heights, the path loss at this range increases at 12 dB/octave range.

Note that in the level graphic, the 43 dB ACIR2 is ascribed to the unwanted signal path, whereas ACIR2 is predominantly a function of the weak UMTS FDD MS RX ACS2.

2.6.3 UMTS FDD Pico BS as Victim (TDD MS -> FDD Pico BS)

In this next example, a UMTS FDD Picocell BS receiver on channel UL14, and an WiMAX Nomadic SS transmitter operating in 2575-2580 MHz, on a carrier frequency of 2577.5 MHz is considered. The two systems are separated by a 5 MHz guard band, as illustrated below.

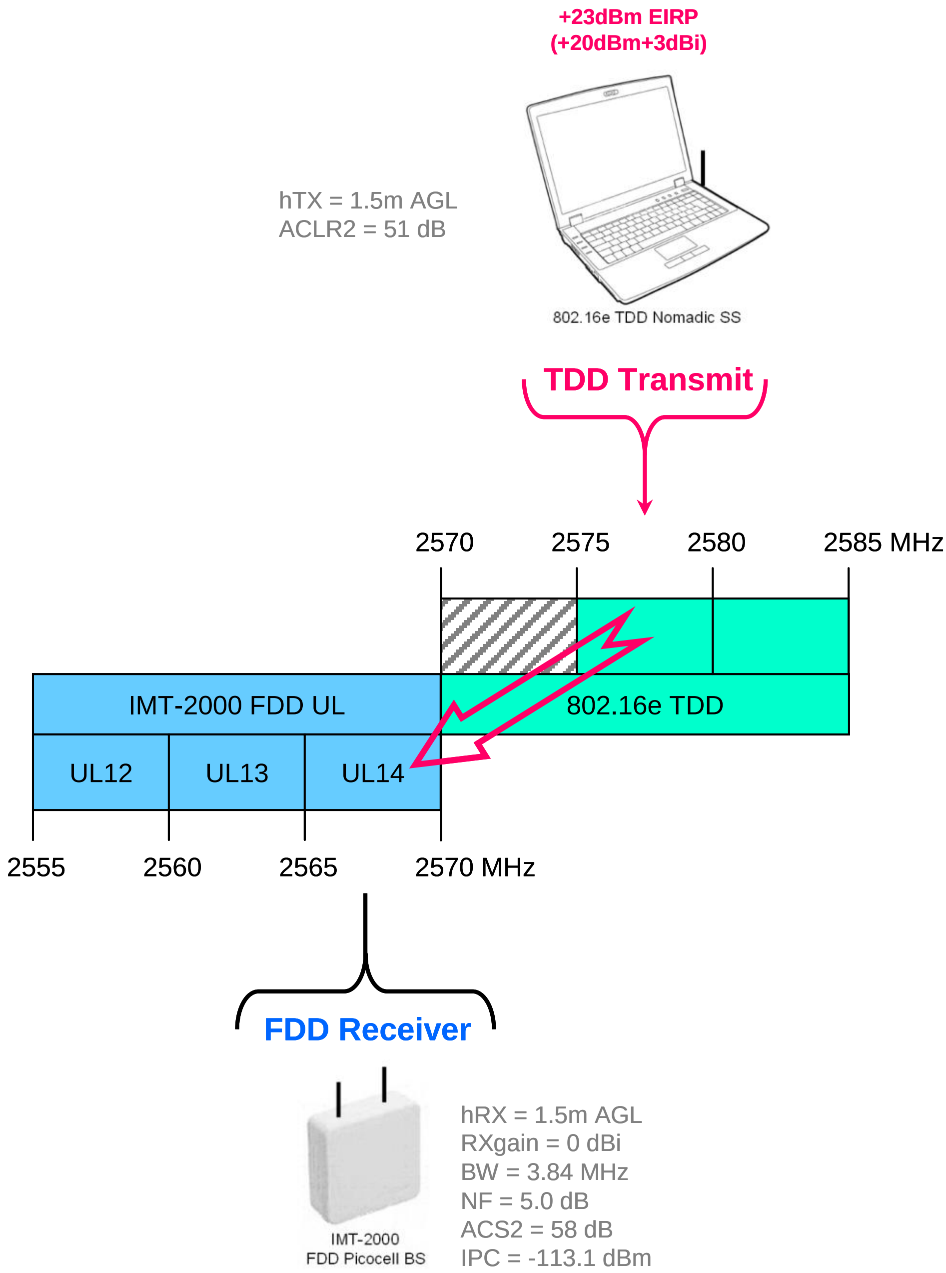


Figure 10 – UMTS FDD Picocell BS as victim (TX = TDD Nomadic SS)

The interference level plan for this scenario is given in Figure 11.

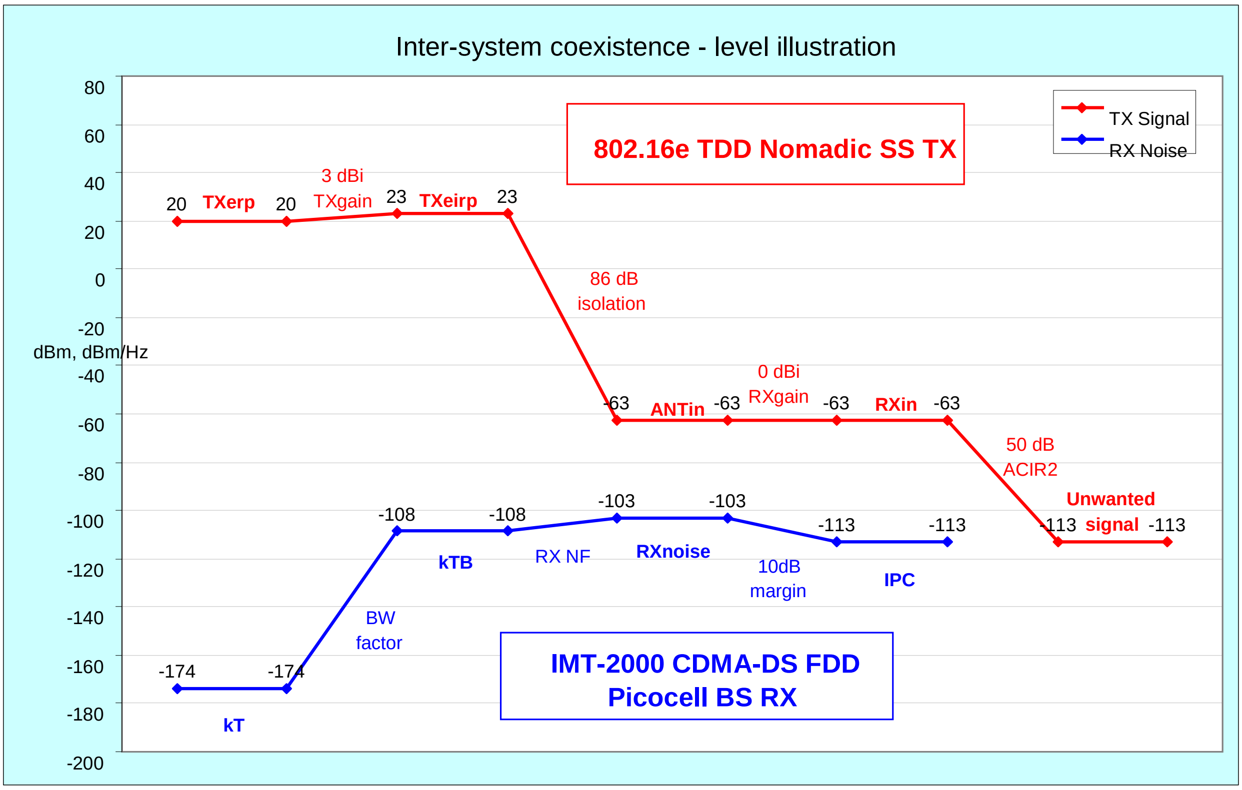


Figure 11 – Levels: FDD Picocell BS as victim (TX = TDD Nomadic SS)

In this scenario, isolation of 86 dB on the 802.16e TDD transmit signal is required in order to meet the IPC_{10} of the CDMA-DS FDD BS receiver. At 2577.5 MHz, to achieve that isolation through path loss of 86 dB would require a separation of 0.12 km, which is outside the dual-slope break-range of 0.08 km based on TX and RX antenna heights.

2.7 RESULTS OF THE ANALYSIS

Coexistence between the UMTS FDD and WiMAX TDD for the scenarios and coexistence cases described in the previous sections have been analysed in detail in [Ref 2]. Two methodologies used in this analysis:

- Deterministic approach, based on the development of interference link budgets for all relevant interference scenarios and cases, and
- Statistical approach, based on a series of Monte Carlo simulations of the same interference scenarios.

A combination of the deterministic and the statistical analysis is often used in coexistence analysis work. The deterministic analysis is a good starting point, as it helps to assess the importance of individual factors, as well as the relative criticality of interference scenarios. However, the deterministic analysis by its nature focuses on the most pessimistic scenarios that may rarely appear in practice. For this reason, the deterministic analysis is often followed by a statistical analysis that looks into practical, changing interference scenarios.

Statistical analysis takes the probability of different interference cases into account, and results in the average performance of the coexisting systems.

The key results of both the deterministic and statistical analysis performed in [Ref 2] are highlighted in the following text, together with the key conclusions of the work.

2.7.1 DETERMINISTIC ANALYSIS

Results of the deterministic analysis are expressed in terms of additional isolation that is required for the two systems to coexist. These tables are reproduced here (from [Ref 2]) for the BS – BS interference (Table 3)

Deployment scenario		**TDD base station ⇒ FDD base station**				
		Co-sited	**100m**	**300m**	**500m**	**1km**
TDD macro/ FDD macro	1st adj chan	70.0	54.3	44.7	40.3	34.3
	2nd adj chan	58.0	42.3	32.7	28.3	22.3
TDD macro/ FDD micro	1st adj chan	23.0	13.8	-4.3	-12.8	-24.2
	2nd adj chan	11.0	1.8	-16.3	-24.8	-36.2
TDD macro/ FDD pico	1st adj chan	11.0	-3.1	-21.3	-29.7	-41.1
	2nd adj chan	-1.0	-15.1	-33.3	-41.7	-53.1
Deployment scenario		**FDD base station ⇒ TDD base station**				
		Co-sited	**100m**	**300m**	**500m**	**1km**
TDD macro/ FDD macro	1st adj chan	78.0	62.3	52.7	48.3	42.3
	2nd adj chan	73.0	57.3	47.7	43.3	37.3
TDD macro/ FDD micro	1st adj chan	26.0	16.8	-1.3	-9.8	-21.2
	2nd adj chan	21.0	11.8	-6.3	-14.8	-26.2
TDD macro/ FDD pico	1st adj chan	0.0	-14.1	-32.3	-40.7	-52.1
	2nd adj chan	-5.0	-19.1	-37.3	-45.7	-57.1

Table 3 – Additional isolation for BS -> BS interference

The results for BS – BS interference are presented as a function of the offset between the base stations belonging to the two interfering systems, in terms of excess interference isolation required for the two systems to coexist. The cases where the excess isolation is negative (the greyed cells in Table 3) are the situations where there is sufficient isolation and coexistence is possible. The underlying assumption is that the UTMS FDD and WiMAX TDD will provide coverage using a similar cellular structure with three sectors and cells of the same size, as shown in Figure 12. There can be an offset between the two overlaid cellular networks, which is equal to the minimal separation between the two interfering BSs belonging to two systems. The results of Table 3 are shown as a function of that offset.

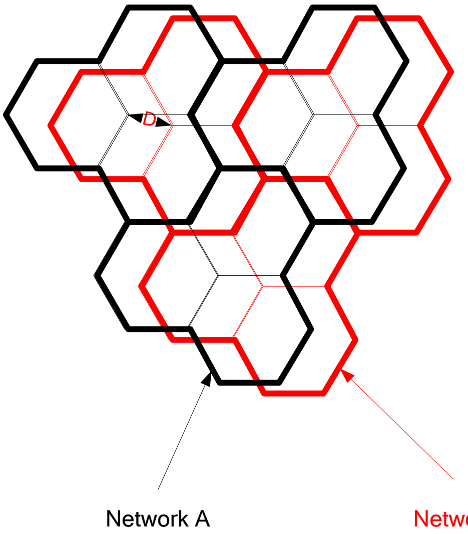


Figure 12 – Two overlaid cellular networks with an offset

Results for BS – MS interference and MS – MS interference cases are given in Table 4 and Table 5, respectively.

Deployment scenario		**Fixed SS => FDD base station**	**FDD base station => Fixed SS**	**Nomadic SS => FDD base station**	**FDD base station => Nomadic SS**	**FDD mobile station => TDD base station**	**TDD base station => FDD mobile station**
TDD macro/ FDD macro	1st adj chan	30.1	45.1	23.3	39.3	22.3	32.3
	2nd adj chan	16.1	35.1	6.3	29.3	12.3	22.3
TDD macro/ FDD micro	1st adj chan	56.2	66.2	43.2	54.2	22.3	32.3
	2nd adj chan	42.2	56.2	26.2	44.2	12.3	22.3
TDD macro/ FDD pico	1st adj chan	54.3	46.3	58.3	55.3	22.3	32.3
	2nd adj chan	40.3	36.3	41.3	45.3	12.3	22.3

Table 4 – Additional isolation for BS <-> MS interference (from [Ref 2])

	Fixed SS => FDD mobile station	FDD mobile station => Fixed SS	Nomadic SS => FDD mobile station	FDD mobile station => Nomadic SS
1st adj chan	53.3	53.3	57.3	59.3
2nd adj chan	42.3	43.3	45.3	48.3

Table 5 – Additional isolation for MS -> MS interference (from [Ref 2])

The results of the deterministic study show that:

- Additional isolation in the 1st adjacent channel is higher then in the 2nd adjacent channel;
- The Macro BS -> BS interference scenario generally has the highest coexistence requirements; this is an additional reason to consider this the most challenging of the coexistence scenarios;
- For the adopted values of coexisting system parameters, there is generally 50 to 60 dB of additional isolation required in the 1st adjacent channel, and 40 to 60 dB in the 2nd adjacent channel for UMTS FDD and WiMAX TDD systems with system parameters given in Section 2.3 to successfully coexist. This additional isolation has to be achieved through some additional interference mitigation techniques (as discussed in Section 3)

To put this result in perspective, a similar amount of additional isolation also exist in FDD – FDD coexistence scenarios. This is illustrated in the following Table (from [Ref 2]).

Deployment scenario		FDD mobile station => FDD base station	FDD base station => FDD mobile station
FDD macro	1st adj chan	21.3	39.3
	2nd adj chan	11.3	29.3
FDD micro	1st adj chan	41.2	54.2
	2nd adj chan	31.2	44.2
FDD pico	1st adj chan	56.3	55.3
	2nd adj chan	46.3	45.3

Table 6 – Additional isolation for FDD BS <-> FDD MS interference (from [Ref 2])

Comparing the values of additional interference isolation required in FDD – FDD interference scenarios (Table 6) with the TDD – FDD scenarios (Table 4) it can be seen that the similar values of missing isolation exist in both systems.

2.7.2 IMPACT OF MICRO AND PICO BS DEPLOYMENT

The values of missing interference isolation for successful TDD – FDD coexistence given in Table 3 also address the issue of interference between the macro BS on one side, and micro or pico BS on the other. The results are summarised in Figure 13.

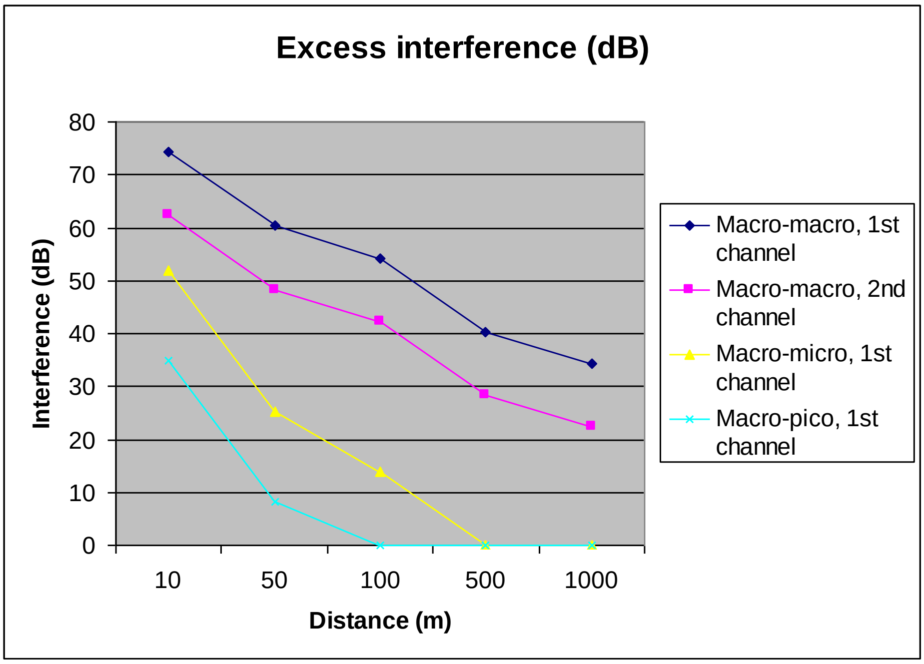


Figure 13 – Required additional isolation, micro and pico BS case

Figure 13 shows that the worst case of excess interference appears in the scenarios with macro BS deployments. The micro and pico deployments have much lower levels of excess interference, and that excess interference decreases more rapidly with distance between the BS in dissimilar systems.

It should be noted that the results of the deterministic analysis reported in [Ref 2] address the TDD macro – FDD micro / pico coexistence scenarios. It is assumed here that these results are equally valid for cases where FDD is a macro station, while TDD is a micro / or pico station.

2.7.3 STATISTICAL ANALYSIS

The statistical approach looks at the performance loss in both UMTS FDD and WiMAX TDD when they are interference victims. The measures used are:

- Capacity loss in UMTS FDD, and
- Modulation efficiency loss and outage rate in WiMAX TDD.

The analysis shows that the BS -> BS scenario is the worst case

Repeated simulation with increased margins show that the extrapolation of results is possible, and this approach is used in Section 3 of this report.

The results of the statistical analysis are expressed in terms of additional isolation, required between the components (BS or MS) of the two interfering systems in order for performance loss in the victim system to be within the acceptable bounds. The acceptable bounds for this performance loss are selected in [Ref 2] as:

- UMTS FDD capacity loss: 5%
- Link outage happens at: target E_b/N_0 - 0.5 dB
- WiMAX TDD average modulation efficiency loss: 5%
- WiMAX frequency reuse scheme: 1x3x3.

Reported simulation results of simulations in [Ref 2] show that the reuse scheme of 1x3x1 is around 5 to 8 dB more resilient to interference. This means that the required additional isolation can be reduced by 3 dB, as discussed in Section 3.

The results of the statistical analysis and simulations given in [Ref 2] are summarised in Figure 14.

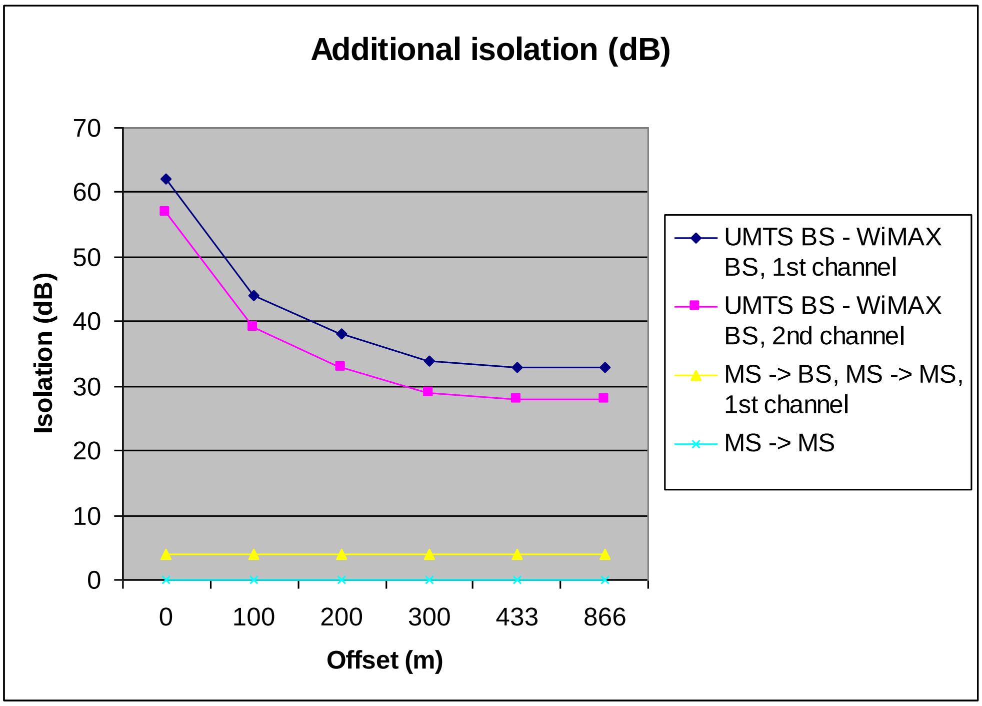


Figure 14 – Required additional isolation

The Figure 14 shows the required additional isolation between the two interfering systems, i.e. UMTS FDD and WiMAX TDD, as a function of the offset between the two cellular deployments. It can be seen that, by far, the additional isolation is dominated by isolation between the BS in the two interfering systems. This short fall in isolation can be as high as 62 dB for two collocated BSs, and is then exponentially reduced with increasing separation. The missing isolation is highest in the first channel (i.e. when two interfering systems operate in the adjacent channels, at either side of the block boundary), and it is approximately 5 dB lower in the 2^{nd} channel (i.e. with one guard band between the two interfering systems).

Other interference scenarios practically need very small amounts of additional isolation. The exception is interference caused by WiMAX MS to UMTS BS, caused mainly by the lower ACS of the UMTS BS, and only in the 1st adjacent channel scenario; additional isolation required here is 4 dB. A similar situation exists with UMTS MS to WiMAX MS, where 3 to 6 dB of additional isolation is required.

In the case of the BS -> MS scenario, no additional isolation is required.

2.8 CONCLUSIONS

In conclusion, the impact analyses of WiMAX TDD – UMTS FDD coexistence are:

- BS – BS interference is by far the worst interference scenario, and the one where most of additional inter-system interference isolation has to be acquired;

- Required additional isolation in the 1st adjacent channel is of the order of up to 66 dB in the case of the collocated macro BS, this falls down to 40 – 45 dB for BS offset by 200 – 300 m in a macro deployment case;

- Required additional inter-system interference isolation is approximately 5 dB higher in the 1st adjacent channel compared to the 2nd channel, which shows that these two cases need to be treated separately.

Additional isolation in BS – BS scenarios helps to alleviate other problems in scenarios involving MS, through power control (i.e. A MS does not need to ramp up the power in order to overcome excess interference from the coexisting dissimilar system). Therefore, once TDD BS – FDD BS interference is solved, most other interference scenarios also become benign (e.g. in terms of less than 5% capacity loss in UMTS FDD).

3 MITIGATION TECHNIQUES

3.1 INTRODUCTION

Coexistence between TDD and FDD broadband wireless access (BWA) cellular networks or between two uncoordinated TDD networks that provide service to the same population of mobile users can be very challenging, due to the mutual (inter-system) interference. The amount of required additional isolation between the two systems is of the order of 60 dB for the worst case interference scenario (TDD macro BS – FDD macro BS). In this section, some of the interference mitigation techniques that can be used to provide this additional isolation are discussed.

The two key techniques that are expected to provide most of the required additional isolation between the TDD and FDD systems in practical situations are:

- Improved ACIR through linearization of the power amplifier (PA) and improved RF filtering, and
- Additional isolation between the BS antennas of the two interfering systems.

When these two key techniques are not sufficient, there are also additional interference mitigation techniques operators may decide to use. These additional techniques are, among others,

- Frequency reuse scheme
- Increased down-tilt;
- Antenna cross-polarization;
- Use of advanced antenna systems;
- Antenna beam-pattern alignment; and
- Mobile handover.

A system operator could combine several techniques from this list to achieve sufficient combined isolation between interfering systems. The choice should be made based on the suitability of each individual technique to a particular BWA implementation, in terms of equipment capability, deployment scenario, target quality of service, etc.

If the proposed mitigation techniques are not sufficient because of extremely strong excess interference, or they are not appropriate in a specific case, the operator of a system that is a victim to interference may decide to accept a small increase in the interference level.

In all situations where there is a risk of mutual interference between the coexisting systems, coordination between the operators of mutually interfering networks has a potential to provide benefits to all parties involved.

3.2 BLOCK BOUNDARY AND CRITICAL CHANNELS

As shown in Section 2, severity of the problem of coexistence between base or mobile stations in two disparate BWA networks covering the same area depends on the frequency separation between the interfering transmitter and the victim receiver. This, in turn, depends on the distance of the transmitter or the receiver's operating channel from the closest edge of the block dedicated to a particular duplex technology (TDD or FDD). The channels that require special attention are the two channels closest to a TDD – FDD block boundary, Figure 15. (Expected division of the 2.5 GHz band to FDD and TDD blocks was discussed in Section 2.2).

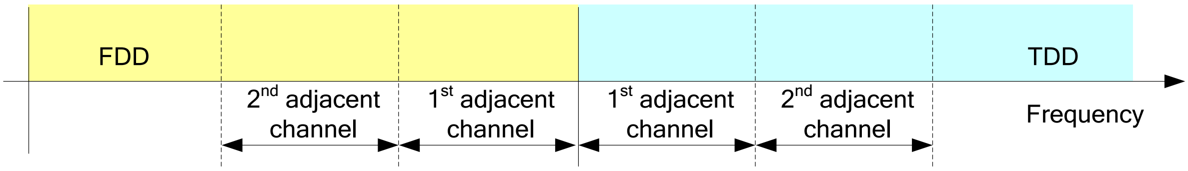


Figure 15 – FDD and TDD channels potentially involved in mutual interference scenarios

Generally, it is the operators that own the 1st and 2nd adjacent channel to a TDD – FDD block boundary that may suffer inter-system interference and may have to consider additional interference suppression measures. These measures are discussed in the following text.

In the current channel plan defined for the 2.5 GHz band each channel is 5 MHz wide, and the following discussions are addressing the UMTS FDD and WiMAX TDD systems with 5 MHz wide channels. The conclusions, however, also hold for wider channels, e.g. 10 or 20 MHz, in terms that the two channels closest to the block boundary at either side are critical and require special attention. Effects of different channel bandwidths are further analysed in Section 4.

3.3 POWER AMPLIFIER LINEARIZATION

Reduction of unwanted emissions of a transmitter in the adjacent channels is potentially an important technique to provide additional isolation between the interfering transmitter and a victim receiver. The reduction of adjacent channel leakage becomes even more important in a situation where the adjacent channel is used by a nearby receiver using a disparate duplex technology. An example may be an FDD transmitter operating at a TDD –FDD boundary, where adjacent channel belongs to a TDD receiver, as shown in Figure 15.

The level of unwanted emissions in an adjacent channel is defined as an adjacent channel leakage ratio (ACLR), and is specified in appropriate standards and other relevant documents, e.g. ITU-R Recommendations M.2116 [Ref 7], M.1580-1 [Ref 8] and M.1581-1 [Ref 9]. The typical ACLR values for UMTS and WiMAX equipment are given in Table 1 and Table 2, respectively, and are not sufficient in inter-system interference scenarios, as already shown in Section 2.

The achievable ACLR values depend on the characteristics of the transmit chain of the interfering receiver. The dominant component of this chain is the power amplifier (PA), whose non-linearity can cause spectral re-growth, i.e. appearance of the 3rd and 5th order intermodulation components that fall into the 1st and 2nd adjacent channel.

The spectral re-growth caused by compression of the PA is illustrated in Figure 16 using the UMTS FDD spectrum as an example. The figure shows both the simulated ideal UMTS spectrum (the line marked "linear" in Figure 16) and distorted spectrum when the PA is driven into saturation (the "1dB Comp" in the same figure). It can be seen from this figure that compression may lead to a significant rise of adjacent channel emissions. In practice, the PA will be operated with some back-off that would put the adjacent channel leakage below the required leakage mask (the "Tx mask" in Figure 16).

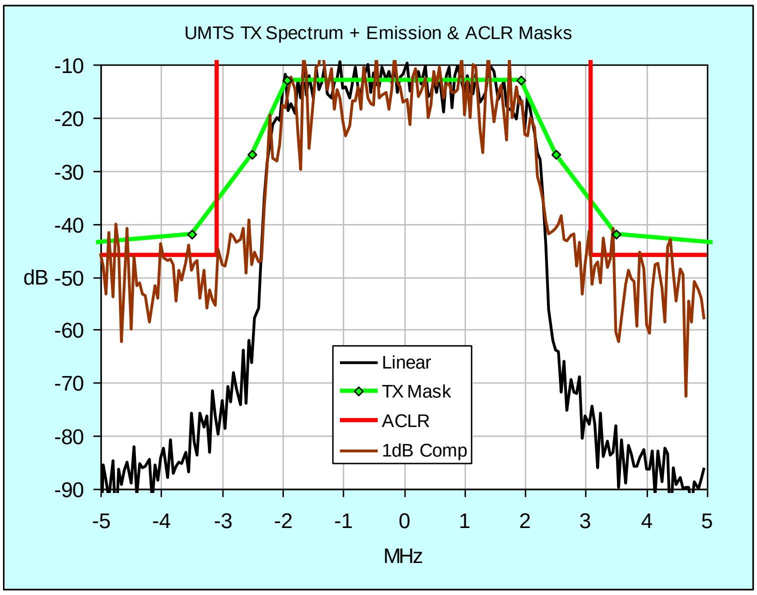


Figure 16 – UMTS Spectra v ACLR and Emission Masks

It can be seen from Figure 16 that the difference between the UMTS FDD ACLR mask (45 dB in the 1st adjacent channel, Table 1) and the actual spectrum of the ideal UMTS waveform potentially leaves a lot of room for PA linearity improvement. A similar situation is with WiMAX, but to a lesser extent, because of the already tighter ACLR requirements.

There are many forms of PA linearization; some of the more commonly used techniques are

- Feed-forward amplification with phase equalization;
- Vector modulator correction; and
- Digital pre-distortion.

More detailed descriptions of PA linearization techniques are given in [Ref 10] and [Ref 11]. One possible PA solution with feed forward amplification is shown for illustration purposes in Figure 17.

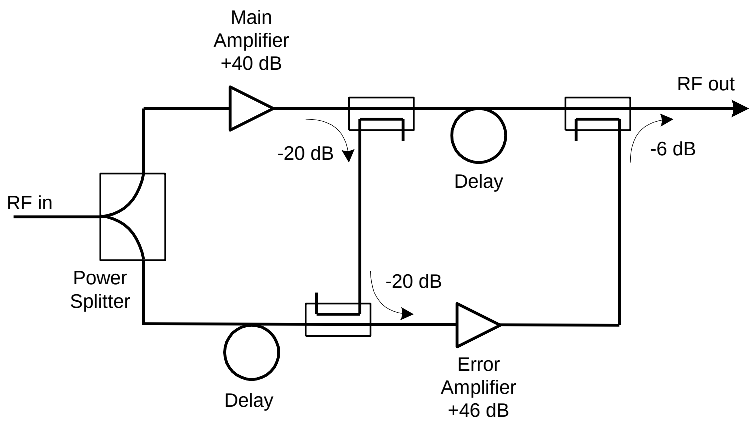


Figure 17 - Conventional feed forward amplifier

The amount of ACLR improvement that is achievable with advanced PA linearization techniques depend on how linear the PA already is before additional linearization measures are implemented, what linearization technique is used, and whether the PA amplifies one or multiple carriers; generally, with an increase of the number of carriers handled by a single PA, improvements in ACLR become harder. Linearization techniques that give better improvement also tend to be more demanding in terms of hardware cost and size, so they may be harder to implement in mobile or subscriber stations. An example described in ITU-R Report M.2045 [Ref 12] gives 18 dB of ACLR improvement in the 1st adjacent channel and 13 dB in the 2nd adjacent channel achievable through PA linearization.

3.4 TRANSMIT FILTERING

The adjacent channel isolation ratio (ACIR) is defined in Section 2.5.4 as a combination of the ACLR and the adjacent channel selectivity (ACS). Both are defined for transmitters and receivers operating in the adjacent channels and using the same duplex technology. In such situation, both the interference source and the victim operate in the same block of frequencies (e.g. both channels belong to a TDD block), so interference suppression caused by filtering comes mainly from IF and base band channelization filters.

Additional suppression of adjacent channel interference can be achieved using single-channel RF filters. Since such filters need to have a high Q factor, they are too bulky and expensive to be used in MS or SS equipment, and are only practical for base station (BS) equipment.

A typical medium-power single-channel UMTS Basestation transmit filter can have an insertion loss around 2 dB, 6 or 7-pole elliptic design, based on tuned-cavity and typically adjusted by hand. The transition band of such filter is of the order of 60 dB/MHz, with more than 60 dB of rejection in the stop-band.

An RF single-channel filter can provide the 60 dB of additional isolation in the 2nd adjacent band, required for TDD – FDD coexistence. It should be noted that single-channel RF filters imply one PA amplifier per RF channel. In a multi-channel implementation, some attention needs to be paid to proper design of a matching network between the single-channel filters and the antennas.

3.5 Receive Filtering

In a similar way to transmit filtering, additional RX filtering can significantly improve adjacent channel selectivity (ACS). Due to the filter size and cost, this is really only practical for BSs.

Receive filters should be employed in conjunction with transmit filtering. In TDD systems, the same filter can perform the both Tx and Rx filtering roles. In FDD base stations, the two filters are commonly combined into a single high-performance FDD diplexer unit.

3.6 Operational Restrictions for Micro and Pico BS

One of the measures to reduce the amount of interference a BS generates is to limit the transmit power or EIRP. For example, the BS EIRP can be limited to 25 dBm / 5 MHz down from 61 dBm / 5 MHz typical for macro BS [Ref 27]. A channel in which a regulator only allows operation of BSs with an EIRP significantly lower than usual is considered restricted. By restricting the maximal EIRP of an interfering BS severity of interference caused by that BS is also significantly reduced.

Reduction of the transmit power has significant implications on the use of the restricted channel. Such a significant reduction of the EIRP means that the cell or sector range is significantly reduced. For this reason, restricted channels are seen as more appropriate for micro base station deployment, with BSs covering a street block in a densely populated urban environment, or a pico BSs deployed indoors. Antennas for micro BS are typically mounted below the roof level, and pico BS are deployed indoors, which means that shadowing and building penetration loss provides additional protection from and to the coexisting system. Micro and pico BS deployments also imply use of antennas with less gain (e.g. an omni indoor antenna).

A combination of the lower transmit power and additional shadowing and building penetration losses means that coexistence problems between the micro / pico BSs on one side, and macro BSs on the other, are much easier to solve. For this reason, restricted channels may be the practical solution for coexistence between systems operating in adjacent channels (the 1st adjacent channel case shown in Figure 15).

Defining a channel as restricted can potentially limit the deployment options for the operator; therefore, the operator has to be aware of the potential of a channel being restricted before applying for a license. The operation of the restricted channel together with a non-restricted 1st adjacent channel may mean that the BS has to suffer increased interference from MSs operating in an adjacent channel and associated to a macro BS. Such MSs can come close to the restricted pico BS while transmitting with high power needed to overcome an indoor penetration loss and reach the distant macro BS. This means that the allocation of the restricted channels has to be done with caution, and in a technology-neutral manner; i,e, both TDD and FDD channels that are adjacent to a TDD – FDD block boundary have to be treated as restricted.

Typical BS EIRP that might be expected in a restricted channel can be of the order of 25 dBm / 5 MHz, which is a 36 dB reduction from 61 dB / 5MHz that might be allowed for a macro BS deployment [Ref 27]. Reduction of adjacent channel leakage is expected to be somewhat less, as cost and size limitations may limit utilization of expensive RF filtering techniques in pico BSs.

3.7 Isolation Between the Collocated BS Antennas

Operators of the two cellular BWA networks often tend to co-locate the base stations. There is a number of practical reasons to do this. For example, there may not be many alternative locations that provide equally good coverage of the same area with easy access to the site and acceptable infrastructure costs; collocation of BS mitigate the near-far effect of adjacent channel interference between the BS and MS; collocated BS can use the same access network; etc. At the same time, as shown in Section 2.7 for a macro BS scenario, collocation needs the most additional isolation, i.e. up to 57 dB in the 2^{nd} channel (it is assumed here that use of the 1^{st} adjacent channel in macro BS collocation is not practical).

Isolation between the two co-located BS antennas can be as low as 30 dB; this value has been adopted for the analysis performed in the ITU-R Report M.2113, [Ref 2] as discussed in Section 2. Careful site engineering can provide additional isolation between the collocated antennas, and can go at least part of the way towards achieving the 57 dB of the missing additional isolation for the collocated TDD and FDD BS. As shown in ITU-R Report M.2045, Annex 2, [Ref 12], by placing the two antennas on the same mast, and with careful coordination, isolation between the antennas can be improved by between 15 and 40 dB, for vertical separation of few metres between the antennas.

It should be noted, however, that for BWA systems that rely on advanced antenna techniques, there may be four or eight antennas covering each sector for each BS. In the case of such multiple antenna installations, it may be impossible to achieve high isolation between all pairs of individual antennas belonging to two BS that are mounted on the same tower structure. In such situations, the limit of additional isolation between the two antenna systems achievable in practice can be between 5 and 25 dB ([Ref 12]).

Based on these discussions, it can be said that antenna site engineering alone is not sufficient to provide the required 57 dB of isolation between the antennas in the case of the collocated mutually interfering BS. A significant isolation has to come from other measures, e.g. from the RF channel filtering.

3.8 Offset in Cellular Network Deployment

In situations where co-location of mutually interfering BS is not feasible due to the insufficient mutual isolation, deployment of two interfering networks with an offset has to be considered. In such a scenario, the required additional isolation between the interfering BS has to come from the path loss between the two nearest BSs belonging to the two cellular networks.

Impact of cellular network offset on missing isolation is discussed in Section 2.7, and deployment of two cellular networks is shown in Figure 12. It is shown there that the missing additional isolation between the two BSs is inversely proportional to distance, and comes down to around 30 dB in the 2^{nd} adjacent channel for BS separation distances about 250 m and greater. Impact of BS separation distance on performance loss has also been a subject of statistical analysis reported in the ITU-R M.2113, [Ref 2]. The following text gives a summary of the results.

3.8.1 WIMAX TDD AS AN INTERFERENCE VICTIM

Dependence of performance loss in overlaid and mutually interfering WiMAX TDD and UMTS FDD networks as a function of the separation of base stations is addressed in [Ref 2] through Monte-Carlo simulations. Effects of separation distance between the BS on system performance have been expressed in terms of system capacity loss for UMTS FDD, and in terms of modulation efficiency loss and outage rate in WiMAX. The effects have also been calculated separately for four possible interference cases: BS->BS, BS->MS, MS->BS and MS->MS. The results depend on the assumed adjacent channel isolation between the two systems and their channel separation, but the performance loss in the victim system shows some general trends. These trends are shown in Figure 18 as a qualitative dependence of the performance loss on spatial offset between the two interfering BWA cellular networks. This offset is equal to the distance between the two nearest BS belonging to the two mutually interfering systems. The cell radius adopted in the analysis is 833 m, and this corresponds to the maximal value of offset.

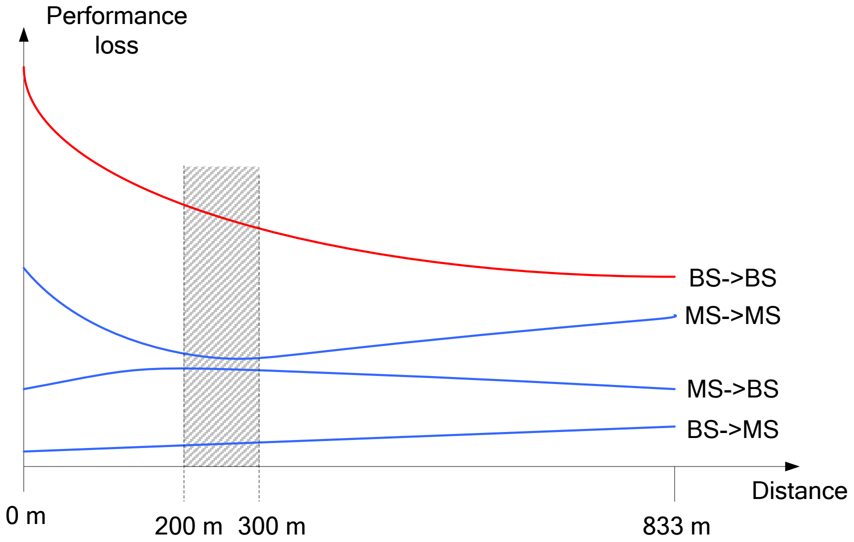


Figure 18 – Impact of UMTS FDD interference on WiMAX TDD vs. the offset of overlaid systems

It can be seen from Figure 18 that performance loss has a different dependence on BS-BS separation for all four possible interference scenarios:

- The dominant performance loss is in a WiMAX TDD BS suffering interference from a nearby UMTS FDD BS. This performance loss monotonically decreases with the increasing distance between the BS.

- The next, in terms of importance, is WiMAX MS suffering interference from FDD MS. Interestingly, the loss of performance shows a shallow minimum for BS separation distances of the order of 200 to 300 m.

- Less critical is interference that WiMAX BS suffers from an FDD MS. This shows even milder maximum for separation distances around 200 to 300 m.

- Finally, the impact on performance of TDD MS in presence of FDD BS interference is very slowly and monotonically increasing with BS separation.

Assuming that the critical interference case is a WIMAX BS suffering interference from the nearest UMTS FDD BS, the best deployment scenario when the base stations are not collocated is to separate the two BS to overcome the excess interference through the additional path loss. It can be seen from Figure 14 in Section 2 that at least 250m of separation is needed to achieve the required isolation. Similar distances, about 200 to 300 m, will also result in minimal MS <-> MS interference, as shown in Figure 18. This numerical value is valid only for the scenario and values adopted in [Ref 2], but it can be argued that optimal separation distance between the interfering BS would be close to 1/3 of the sector range for other cell radii expected in practice; e.g. larger cell radius would mean higher EIRP of the interfering BS and therefore larger separation distances needed to protect the victim BS.

It should be noted that separation distances of 200 – 300 m are also the distances where BS suffer most interference from MS belonging to the other system. Results of Monte-Carlo simulations given in [Ref 1] do not seem to show this being a significant contributor to the overall BS performance loss. If it is possible to provide sufficient isolation between the antennas in a scenario when interfering BSs are collocated, this collocation of the BSs will result in minimal interference caused by MSs from the other system.

Interference that MSs suffer from BSs has a minimum for BS separation distances of 200 to 300 m, while interference caused by MSs in the other system monotonically rise with BS separation. The co-existence interference mechanism that will dominate MS performance (MS to BS or MS to MS) will depend on MS's BEM. This, in turn, may define whether BS collocation or separation by 1/3 of sector range is better from the MS point of view. It should be noted, however, that interference suffered by the BS should be considered a more critical factor in system design, and that some MS performance loss is inevitable in cases when there are active MSs nearby that belong to the other system.

3.8.2 UMTS FDD AS AN INTERFERENCE VICTIM

The similar diagram, showing the qualitative impact that separation of UMTS and WiMAX BS has on the UMTS FDD system performance loss is shown in Figure 19 for all four interference scenarios.

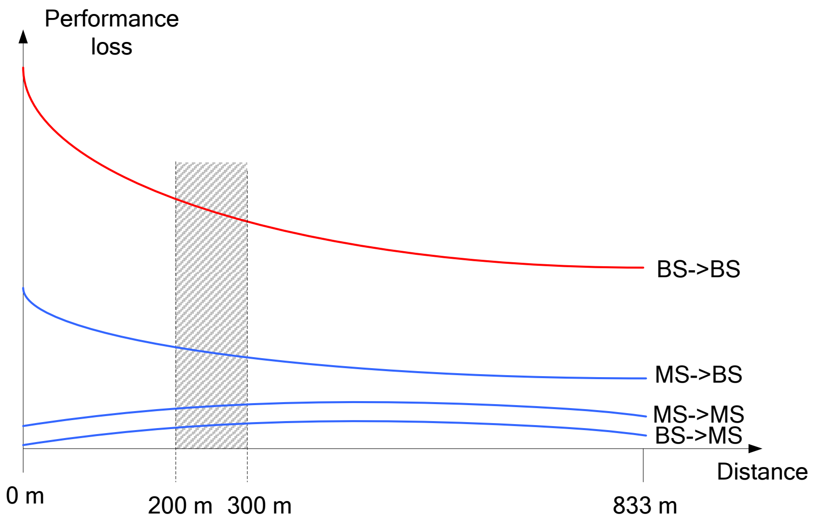


Figure 19 – Impact of inter-system interference vs. BS distance of overlaid systems on UTRA FDD

In scenarios where UTRA FDD is a victim from WiMAX TDD interference, there is a trend of decreased impact on BS performance loss with the increased BS – BS distance, and a very mild maximum in MS performance loss when BS separation is close to half the sector range. This indicates that the FDD operator may prefer minimal separation between the co-existing BSs, just sufficient for them to coexist (e.g. closer to 200 m). Alternatively the best results in terms of impact on MS will be achieved with collocated BSs, if that is possible due to the BS interference.

3.9 Use of Advanced Antenna Systems

Advanced antenna systems (AAS) implemented in either a victim or an interfering BS can potentially provide significant interference suppression. An example is beamforming, where the interfering BS can concentrate its radiated energy towards the served MS (and hence away from the victim BS), while the victim BS can create a null in the radiation pattern in the direction of the interfering BS. In principle, the beamforming can be implemented in a MS, if that device has multiple antennas; this, however, is not expected to be common in practice, as beam forming techniques are often computationally intensive.

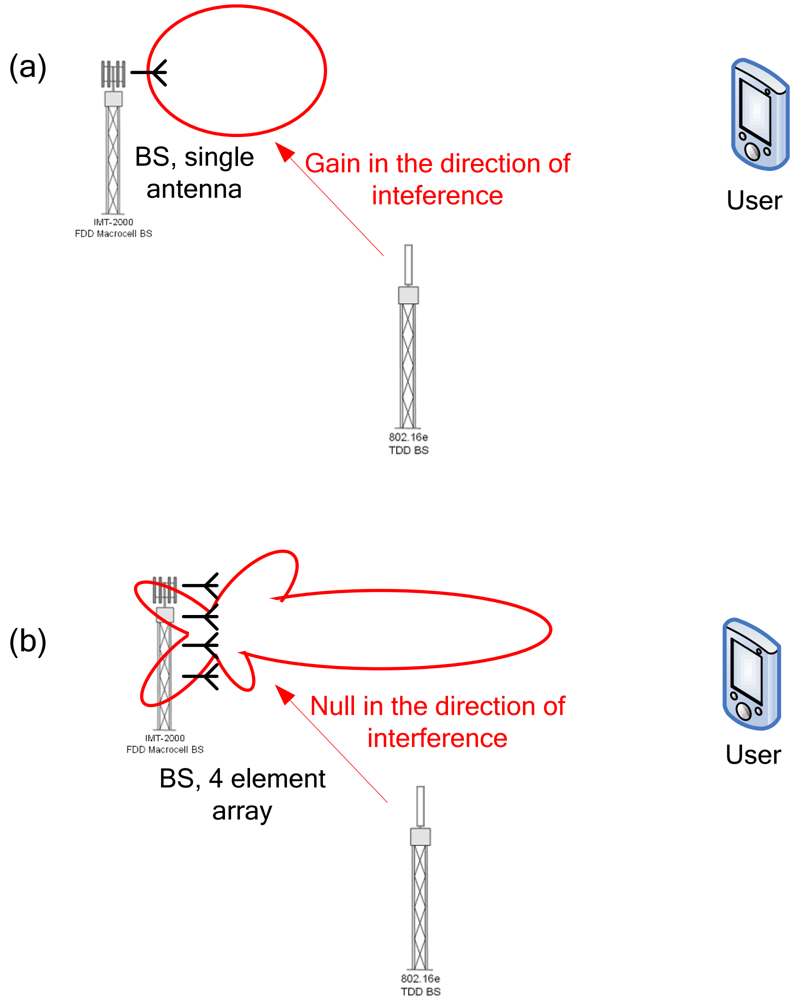


Figure 20 – BS antenna radiation pattern (a) without beamforming; (b) with beamforming;

The mechanism of BS antenna beamforming is illustrated in Figure 20. In the scenario illustrated in (a) the BS antenna covers the whole served sector. The maximum antenna gain is directed towards the user, but there is also a significant gain towards the interferer, and the BS antenna discrimination is relatively small.

In the scenario shown in Figure 20 (b), the base station is using beamforming. This gives the opportunity to increase the antenna gain towards the served user, while, at the same time, a null in the antenna radiation pattern is created in the direction of the incoming interference.

It should be noted that achievable interference suppression due to the beamforming depends on the direction of arrival of the interfering and the desired signal. If the angle between the two is small, the antenna may not be able to discriminate between them, and the resulting interference suppression will be smaller.

In a simplified scenario where there is just one user and one interferer with well separated directions of arrival, significant interference suppression (up to several tens of dB) can be achieved using beamforming. In practice, when the BS has to serve a large number of users, additional isolation that can be achieved using beamforming can be approximated as $10 \log_{10}(M)$, [Ref 12], where M is the number of antenna elements. For an antenna array of 8 elements at the BS site, this gives an average isolation of 9 dB.

Other AAS techniques, such as MIMO, are not expected to provide any additional isolation over the use of a single antenna. For this reason, MIMO should be combined with beamforming at the BS that is suffering interference. If similar beamforming techniques are used at the BS that is causing interference to the BS at the known location, another $10 \log_{10}(M)$ of interference isolation can potentially be achieved.

It should be noted the isolation that can be achieved in practice depends on a number of factors such as severity of multipath on both the desired signal and interference, whether there are active users close to the interfering or victim BS that belong to the other system, etc. All these factors mean that achievable interference isolation, for some users can occasionally be less than the values derived above.

In an interference-limited environment, MIMO cellular systems may become more vulnerable to interference, and suffer more capacity loss as the number of antennas increase ([Ref 14], Section 5.6.3). This may lead to a situation where, when coexisting FDD and TDD systems both use spatial multiplexing and high order MIMO systems, they may be more vulnerable to mutual interference than the simulation results derived for SISO systems would indicate.

3.10 FREQUENCY REUSE SCHEME

Results of Monte-Carlo simulations reported in [Ref 2] indicate that the capacity and modulation loss caused by mutual interference between WiMAX TDD and UMTS FDD systems depends on the frequency reuse scheme implemented in the WiMAX BS.

The main candidate frequency reuse schemes are:

- 1x3x3: Each BS site is divided into three sectors. Each sector uses 1/3 of one (e.g. 5 MHz wide) channel. Frequency reuse factor is 1, i.e. the same channel is used in all cells.

- 1x3x1: Similar to 1x3x3, but each cell also uses all subcarriers in all sectors.

These two frequency reuse schemes are shown in Figure 21.

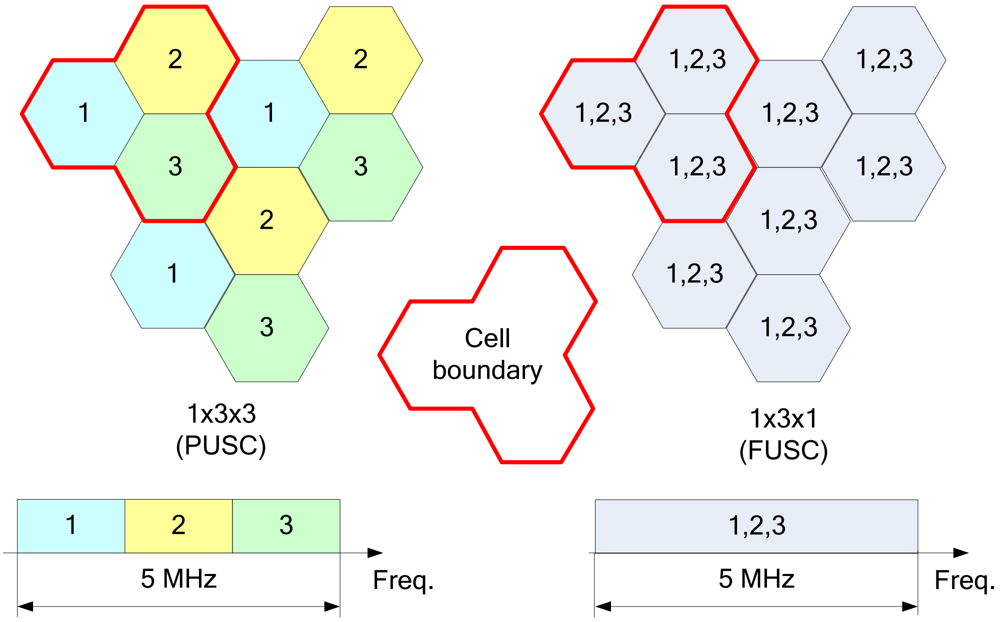


Figure 21 – WiMAX candidate frequency reuse schemes

Results of simulations given in [Ref 2] indicate that the 1x3x3 frequency reuse scheme is more vulnerable than 1x3x1 in terms of efficiency loss, but slightly less vulnerable in terms of link outage rate. When WiMAX is deployed in the same area as UMTS FDD, the WiMAX operator has some scope to trade off the efficiency loss for the outage rate. The increased outage rate will probably be more noticeable by the users, while lower efficiency may be of more concern to the network operator.

In absolute terms, simulation results in [Ref 2], Table 2.5.4.1-4 show that 1x3x1 frequency reuse scheme is more robust than the 1x3x3 scheme by a margin of about 7 dB. This is explained by the fact that 1x3x3 scheme is more sensitive to the adjacent channel interference even in the absence of additional DS-CDMA interference.

The similar margin of around 7 dB of 1x3x1 scheme over 1x3x3 is noted in the capacity loss in UMTS FDD caused by WiMAX with BSs that are not collocated (i.e. with about 250 m of separation between adjacent BSs in the two interfering systems).

3.11 INCREASED BS ANTENNA DOWN-TILT

Selection of the down-tilt of the macro BS antenna is a well-known mobile network optimisation technique. In the absence of any interference from adjacent cells, optimal performance (in terms of minimal required BS transmit power) would be achieved by pointing the antenna towards the cell edge. In practice, interference from adjacent cells can be significant in cellular systems with low frequency reuse factor (e.g. 1 in WCDMA), so increasing the BS antenna down-tilt can reduce the interference to and from adjacent cells. The penalty of increased down-tilt is reduced antenna gain towards the MSs that are close to the edge of coverage, which in principle needs to be compensated by an increased transmit power; this, in turn, increases the inter-cell interference. There is an optimal value of down-tilt that maximises system capacity, and it depends on the amount of inter-cell interference at each particular BS location.

Two techniques to down-tilt a BS antenna are mechanical and electrical down-tilt. Electrical down-tilt is preferred, as mechanical down-tilt leads to an up-tilt of antenna back lobes and increased interference from that direction. More subtly, electrical down-tilt reduces the BS's antenna radiation pattern in all directions, including the sector edges, proportionally; in the mechanical down-tilt, the radiation pattern at the edges is less affected than the main direction of the beam. In a deployment scenario where coexisting FDD and TDD BS are not collocated, interference from the nearest interfering BS comes from the direction of the border between the two sectors of the victim BS; therefore, electrical down-tilt can produce more BS-BS interference suppression for the same loss of cell coverage caused by down-tilt.

Another technique that can potentially help to reduce the interference coming from an adjacent disparate BSs is to point the victim's antenna slightly away from the interference source in the azimuth, as well as elevation. This is expected to be less efficient than down-tilt: with down-tilt, the served MS and the interfering BS are seen by the interference victim BS antenna as being at different elevations, and increasing the down-tilt suppresses interference more than the desired signal. In azimuth, both the served MS and the victim BS are seen at the same azimuth, and the loss of victim BS's antenna gain is the same for both signal and interference.

No results on capacity gains caused by additional BS antenna down-tilt in a FDD and TDD coexistence scenarios have been found in the available literature. For CDMA–only interference scenarios, capacity gains of up to 58% have been reported. In TDD–FDD scenarios, this capacity gain is expected to be manifested as a reduced capacity loss caused by interference from a disparate system.

3.12 ANTENNA CROSS-POLARISATION

In theory, if two interfering systems (FDD and TDD) use orthogonal polarisation for their respective BS antennas, 10 to 15 dB of additional isolation in BS-BS interference scenario can be expected. In practice, with multiple input – multiple output (MIMO) antenna techniques that are expected to be widely used in future BWA networks, some performance gain can be achieved through improved antenna diversity if orthogonally polarised antennas are used in each BS. This will, in turn, limit the usability of polarisation discrimination in practical scenarios.

3.13 Antenna Beam Pattern Alignment

With coordination between the operators of disparate BWA systems, it might be possible to organise their frequency plans so adjacent channels will not be used in adjacent BS in sectors where BS antennas are pointing towards each other. With the main lobe of e.g. interfering antenna pointing to back lobes of the victim antenna, there will typically be 30 dB of interference suppression due to the front-back ratio of the victim antenna. Additional interference suppression may be achieved if the back lobe nulls in the radiation pattern can be used.

As in other techniques, this approach assumes that the operator of the victim system has enough spectrum available so he can change the frequency plan on the victim site. This technique also assumes some level of coordination between the operators of mutually interfering systems in cases where they both need to make changes to their frequency plans.

3.14 Mobile Handover

In a situation where interference exists only between some pairs of coexisting BSs (the ones that are close in terms of both distance and frequency separation), it may be possible to mitigate the loss of capacity in the victim cell by handing over some of the MS traffic to the neighbouring BS, assuming that one uses channels with more favourable interference situation. This technique can be seen as only a partial solution, as it is equivalent to a reduction of coverage of the victim BS, combined with an increased load of the neighbouring BS; therefore, the overall capacity of the cellular system is thus reduced. Also, this technique has to be less efficient in deployments with lower channel reuse factor; in the quite possible scenario of WCDMA channel reuse of 1 and WiMAX channel reuse of 1x3x1 or 1x3x3, the same RF channels are used in all cells in both systems.

3.15 Half Duplex FDD Operation

Schemes where an FDD system is operating in a channel at an FDD - TDD boundary where it transmits, or receives, synchronously with a neighbouring TDD system, only in slots where it neither causes nor suffers interference is described in [Ref 26], Section 2.2. Such schemes cause an inevitable loss of capacity (40 or 60% if TDD system is WiMAX with the downlink / uplink subframe ratio of 28/19), but it can be seen as an alternative to using a channel as a guard band.

3.16 Acceptance of Higher Interference Levels

One of the measures that can be adopted in the situation of mutual interference between the two disparate BWA systems is to simply accept the increased level of external interference in the victim system. The action of adopting the higher levels of interference, however, is not seen as a preferred one, as it may have a serious impact on the affected system capacity and performance.

In CDMA systems, control of the number of users allowed in a cell is based on the ratio of perceived interference plus noise over noise only on the uplink, defined as noise rise. The measured interference is the sum of the interference from users in he same cell (intra-cell) and the inter-cell interference. Typical value of allowed noise rise is 6 dB, after which the new users are not admitted in the affected cell. In a scenario where there is another, e.g. TDD system, causing additional interference, this will be seen by the CDMA BS as additional noise rise, and the BS will combat it by reducing the cell capacity. In the worst case, the additional TDD interference can be allowed to be equal to thermal noise, causing 3 dB of noise rise alone. This value of 3 dB WCDMA receiver desensitisation at I/N = 0 dB has been used e.g. in the ECC report [Ref 3].

In scenarios where the MS is the interference victim, raised levels of interference on the downlink is inevitable, especially in situations where a nearby MS belonging to a disparate system is the interference source. In such situations, loss of link capacity for that individual user is something that is hard to avoid.

3.17 Coordination Between the Operators

From the regulator's point of view, mutual cooperation of the operators of interfering TDD and FDD BWA systems is probably a preferred method to facilitate coexistence. By coordinating the locations of their BS and their frequency plans, the operators can come up with an optimal solution that will minimise the impact that mutual interference has on their respective systems. However, operators in practice may not be ready to cooperate, especially in situations where their respective systems suffer different performance loss due to the mutual interference. In such situations, it is quite possible that absence of cooperation can lead to a situation where both operators suffer significant loss of the performance of their respective systems due to the lack of coordination.

In such scenarios, involvement of the regulator may be required to resolve the issue. The regulator knows what channels are at the TDD-FDD boundary, and knows that operators providing BWA service in those channels may face coexistence problems. The regulator can then set requirements for coordination between the operators (e.g. in channel planning) as part of the licence for these channels. It can also provide an enticement for them, e.g. as the relaxation of the out-of-block emission requirements, if both affected operators agree accept the risk of higher interference coming from the other system (which they will presumably mitigate through a coordinated frequency plan and BS deployment).

The regulator also has an interest in enticing the operators to coordinate, because it gives him an opportunity to achieve a greater economic value from those boundary channels that can otherwise end up as guard bands, with no interest from spectrum bidders.

It should be noted that, in some situations, the expectation of interference management may be directed to one operator more than the other, e.g. because it is easier for him to implement the interference control measures. This is another reason why involvement of the national regulator may be important.

3.18 Coexistence Scenarios

This section gives three examples of UMTS FDD and WiMAX TDD system coexistence in the same area, that can be achieved through a combination of appropriate interference mitigation techniques described in the previous text.

3.18.1 CO-LOCATED BASE STATIONS

In this scenario, the UMTS FDD and WiMAX TDD macro base stations are co-located. The scenario is illustrated in the following figure.

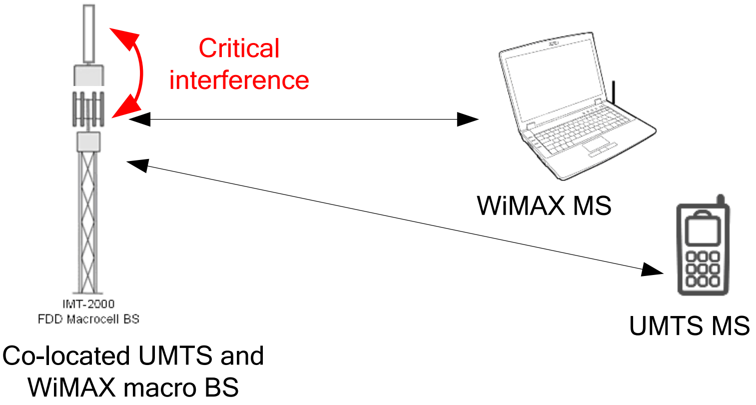


Figure 22 – Collocated macro UMTS and WiMAX BS

The coexistence measures implemented are:

- Frequency separation: 5 MHz guard band (2nd adjacent channel scenario)
- Improved antenna isolation: 20 dB
- RF channel filtering: > 40 dB

The combination of these three interference mitigation measures can provide additional isolation in the excess of 60 dB. The required additional isolation for the two co-located macro BS to coexist is 57 dB in the 2nd adjacent channel (see Figure 14), so coexistence with the applied measures is seen as feasible.

3.18.2 SPATIALLY SEPARATED BASE STATIONS

In this scenario, there is offset of 250 m between UMTS FDD and WiMAX TDD macro base stations. The scenario is illustrated in the following figure.

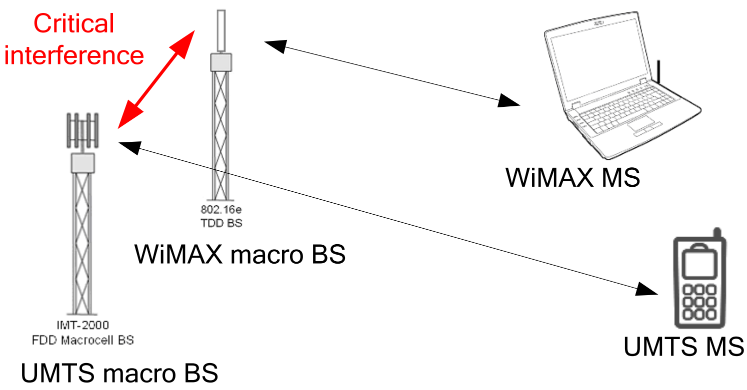


Figure 23 – Spatially separated macro UMTS and WiMAX BS

The coexistence measures implemented are:

- Frequency separation: 5 MHz guard band (2nd adjacent channel scenario)
- Improved power amplifier linearity: 15 dB
- Additional isolation through beamforming or filtering on both BS sites: 18 dB

The combination of these three interference mitigation measures can provide additional isolation of 33 dB. The required additional isolation between the two macro BS that are 250 m apart is close to 30 dB in the 2nd adjacent channel (see Figure 14), so coexistence with the applied measures is seen as feasible.

3.18.3 PICO BASE STATIONS DEPLOYED IN RESTRICTED CHANNELS

In this coexistence scenario, a pico BS is deployed indoors in a restricted channel adjacent in frequency to an interfering macro BS. The coexistence scenario is illustrated in the following Figure.

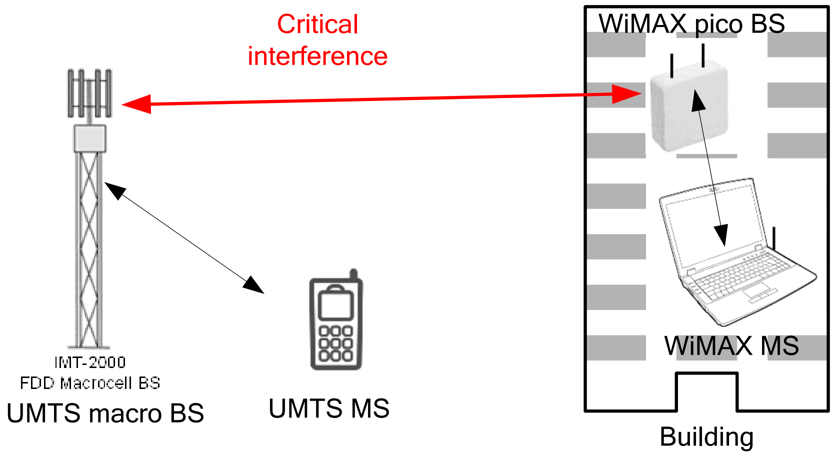


Figure 24 –Macro – pico coexistence scenario

The coexistence measures implemented are:

- Frequency separation: no guard band (1st adjacent channel scenario)
- Micro BS deployment: 35 dB less EIRP, compared to the macro scenario
- Building penetration loss: 15 dB (ITU-R P.679-3 [Ref 22])
- Near-far gain (i.e. the interfering BS being further away from the indoor BS than the associated MS): 20 dB

The combination of the interference mitigation measures gives 35 dB of additional interference isolation when the pico BS is an interference source, and 35 dB of isolation when it is a victim to interference. The required additional isolation between the two macro BS that are 250 m apart is approximately 35 dB in the 1st adjacent channel (see Figure 14), so coexistence with the applied measures is seen as feasible.

3.19 CONCLUSIONS

The conclusions of the interference mitigation techniques between the coexisting TDD and FDD BWA systems in the 2.5 GHz band are:

- The worst case scenario for coexistence of two BWA systems that use disparate duplex methods (TDD and FDD) in the same geographical area is interference between the BS in the two systems.

- A significant part of the required additional isolation between the interfering systems has to be provided through improved adjacent channel leakage of the interfering transmitters and improved adjacent channel selectivity of the interference victim. This can be achieved through improvements in power amplifier linearity and RF filtering. One way of formulating the requirements in this area in practice is through imposing the block edge emission masks.

- Co-location of the interfering BS requires sufficient isolation between them. This can be achieved through a combination of RF channel filtering and careful site engineering in order to achieve sufficient isolation between the antennas. The need of RF filtering implies a need of a guard band between the two systems, e.g. one 5 MHz wide channel of frequency separation between the collocated BS.

- If sufficient isolation for co-located BS cannot be achieved, the interfering TDD and FDD networks can be deployed with an offset, thus providing an element of spatial isolation between the interfering BS. Distances of around 250 m or more are expected to be sufficient in macro BS scenarios similar to the one analysed in ITU-R Report M.2113, [Ref 2].

    - Lower distance between the BS reduces the BS-MS interference, but increases the BS – BS interference problems.

    - Additional isolation can be provided using increased BS down-tilt.

  FDD MS to TDD MS interference seems to show minimal impact for macro BS separations of the order of 200 to 300 m. The optimal separation between the two interfering cellular systems might be in that range of BS distances.

  If needed, additional isolation can be provided using other advanced techniques discussed in this section, or accepting increased interference in the victim BS. It should be noted, however, that increased interference has a negative impact on system capacity.

- The first adjacent channel TDD - FDD scenarios require special attention. Such adjacent channels can be used as restricted channels, i.e. for micro or pico-BS deployment.

- Some MS-MS interference is unavoidable in all situations. However, Monte-Carlo simulations of [Ref 1] show that a relatively small number of users (the ones in close proximity to each other) will be affected. The effects are also transient in nature; i.e. the users can in principle move away from each other to avoid interference.

- It is always advisable to have coordination between the operators that might cause and suffer mutual interference. The operators may decide to coordinate their frequency plans in order to avoid using adjacent channels in collocated BS. They might be reluctant to do so, as this imposes an additional limitation to their frequency plans and can reduce the network capacity. Also, in some scenarios operator of one system may suffer more interference than the other. For this reason, the regulator that wants to promote a technology-neutral approach could also entice the operators of disparate systems to cooperate in the network deployment, i.e. by allowing them to use less stringent emission masks if they do. It should be borne in mind that in some situations coordination might not be feasible, as one of the operators might only have access to few channels; in such cases, the burden of coordination may lay more heavily on the operator with more degrees of freedom.

4 SENSITIVITY ANALYSIS

4.1 INTRODUCTION

The discussions of coexistence scenarios and interference mitigation techniques given in this document are primarily based on the results and discussions given in the ITU coexistence study report, [Ref 2]. Those findings, in turn, are derived from a defined set of basic assumptions and values of parameters discussed and listed in sections 2.1, 2.2 and 2.5 of the [Ref 2]. This section gives a qualitative analysis of the sensitivity of the conclusions derived in this report on those basic assumptions, in order to assess the robustness of the proposed interference mitigation techniques. The issues that are analyzed in this section are:

- Impact of bandwidth of the interfering systems;
- Impact of specified adjacent channel leakage ratio and selectivity;
- Impact of the assumed transmit power, antenna gain and height; and
- Impact of the propagation environment between the BS;

There are very few results on the impact that variation of system parameters have on UMTS FDD – WiMAX TDD coexistence in available literature. For this reason, the following discussion has to be limited to qualitative analysis.

4.2 IMPACT OF BANDWIDTH

Results of coexistence environment analysis presented in Section 2 and mitigation techniques in Section 3 are given with an assumption that channel bandwidths of the two interfering systems (UMTS FDD and WiMAX TDD) are both 5 MHz. It is expected, however, that future BWA systems (both WiMAX and LTE) will gradually move towards wider channel bandwidths, e.g. 10 or 20 MHz, as these wider bandwidths potentially provide the users with higher data rates. It is presumed that an individual operator has access sufficient bandwidth to be able to implement those wider channel bandwidths; the issue of the available bandwidth can, e.g. lead the operator to prefer some frequency reuse schemes over others. Also, the channel plans in the 3.5 GHz or 470-862 MHz may favor channel bandwidths different from the 5 MHz radix, for example pans based on 7 or 8 MHz channel bandwidths.

Generally speaking, impact of WiMAX system bandwidth on its ability to coexist with an FDD system depends on the amount of interference power it generates in the adjacent channel, or the amount of interference power it receives from an interfering system in the adjacent channel; in other words, it is defined by the ACLR and ACS.

WiMAX as an interference source. The total interference caused by WiMAX into an adjacent UMTS FDD system is a combination of interference power in the WiMAX band (defined by UMTS ACS) and in the UMTS band (a function of WiMAX ACLR). Spectrum emission masks defined in ETSI EN 302 544-1, [Ref 24] which are fulfilled by WiMAX, take into account the fact that wider BS bandwidths lead to lower spectral emissions in the adjacent bands. Adjacent channel leakage ratios are defined as the same for both 5 and 10 MHz bandwidth options.

An increase in the emission bandwidth generally results in a proportional increase in the of intermodulation components bandwidth, caused by the non-ideal WiMAX power amplifier. Again, with ACLR defined and measured over the increased channel bandwidth, the same ACLR requirement for both 5 and 10 MHz bandwidths imply the same amount of total interference power leaking into the adjacent victim channel.

WiMAX as an interference victim. Generally an increase in the WiMAX system bandwidth means that the receiver can receive more total interference power due to the larger bandwidth. At the same time, however, the interference protection criteria will increase, as total noise power in a channel will also go up. These two effects will effectively cancel each other out, thus making the component of interference into a WiMAX receiver caused by UMTS FDD ACLR effectively independent of the WiMAX channel bandwidth.

As a conclusion, the channel bandwidth of the interference source and victim is expected to have a little impact on the issues of coexistence between the TDD and the FDD systems. Therefore, the conclusions derived in the sections 2 and 3 are not seen as sensitive to the bandwidth of the two coexisting systems.

4.3 Adjacent Channel Selectivity and Filtering Requirements

The ACLR and ACS specified for the two systems have a major impact on the possibility of coexistence between the two interfering systems.

Worse ACLR and ACS. Relaxation of the adjacent channel selectivity can be a result of less selective IF and baseband filtering being used in the interference victim receiver; higher out of band leakage can be caused by less back-off in the power amplifier of the interfering transmitter. Any relaxation of the requirements imposed on the equipment in macro cellular deployments can have a serious impact on possible coexistence, as even with the currently considered ACLR and ACS values for UMTS and WiMAX, a combination of additional interference suppression measures need to be implemented in both coexisting systems. The relaxation of requirements is less critical in pico, and to a lesser extent, micro BS equipment, as the effects of interference are local, and a significant part of additional interference isolation is expected to come from building penetration losses and shadowing.

Better ACLR and ACS. Improvement of the ACS through better filtering and reduction of ACLR through a combination of improved filtering and better linearity of power amplifier is a significant enabler of coexistence between the interfering TDD and FDD systems. One way for a regulator to impose tighter requirements is through Block Edge Masks (Appendix A). However, a proper balance has to be found, as very tight selectivity requirements may significantly contribute to the cost of equipment.

Specification of the ACLR and ACS has to be carefully traded off with other interference suppression techniques, in terms of the potential cost impact and feasibility. These two factors, particularly the achievable ACLR, have a major impact on the applicability of conclusions derived in this report and practical coexistence feasibility.

4.4 TRANSMIT POWER, ANTENNA GAIN AND HEIGHT

These factors have a major impact on feasibility of TDD – FDD coexistence, hence on the validity of coexistence conclusions as well.

Transmit power of the interferer are defined by the power classes of the equipment that is the source of interference, and, indirectly, to the BS deployment scenarios (macro / micro / pico). Lower in-band transmit power of the interferer does not necessarily lead to an equivalent reduction of the adjacent band leakage, as it is expected that the equipment belonging to the lower power class will have somewhat relaxed ACLR mask, and ACLR is seen as having a greater importance for coexistence than ACS. Generally, peak transmit power of the interfering BS is defined by the coverage, and is not seen as a flexible parameter.

Antenna gains of both the interference source and victim are significant in coexistence scenarios. What is important is the transmit and receive antenna gains towards each other in the critical interference scenario, and reduction of this gain has a significant positive impact on TDD – FDD coexistence feasibility; some of the techniques describing how this can be achieved are given in Section 3. In SISO scenarios, antenna gains of both BS and MS are defined by the requirements of coverage, and are not expected to change much from one implementation to another. When advanced antenna (e.g. MIMO) techniques are used, interference environment becomes more varying and less predictable. A combination of MIMO with beamforming is expected to contribute to FDD – TDD coexistence, and is one of the important interference mitigation techniques, as described in Section 3.9.

4.5 PROPAGATION ENVIRONMENT

The interference propagation environment is seen as an important factor in TDD – FDD coexistence. The most challenging coexistence scenarios are between the BS in two mutually interfering systems deployed at close range, which implies free-space propagation loss between them. The free-space model is therefore used in most coexistence studies, including the Draft ITU Report [Ref 2]. Most other interference scenarios, e.g. between the MS, or between the macro and micro BS, can benefit from the additional path loss.

Multipath propagation can have a two-fold effect on the feasibility of interference mitigation measures suggested in Section 3. In a situation where there is no single well-defined interference path, but the interfering signal is arriving at the victim receiver scattered from a multitude of directions, interference cancellation through beamforming can become ineffective. On a positive side, if slow fading is present on the interference path, adaptive modulation and coding techniques can provide higher throughput during the periods of interference fades.

5 STANDARDISATION AND REGULATORY ACTIVITIES IN EUROPE

5.1 INTRODUCTION

The subjects of broadband wireless access systems, best usage of the UHF, L and S bands, technology neutrality and spectrum administration that is most appropriate to the public needs in light of the rapidly evolving technology, are all addressed by the current standardization activities in Europe. In this section, a brief overview of the current status of these activities is given, with a focus on:

- CEPT Electronic Communications Committee activities within the Project Team 1;
- ETSI work within the Broadband Radio Access Networks standardization project; and
- CEPT activities, coming from an EC Mandate, in the area of spectrum policy on WAPECS.

A brief description of the current activities in these three areas is given in the following text.

5.2 ECC PT1 ACTIVITIES

The Electronic Communications Committee (ECC), part of the European Conference of Postal and Telecommunications Administrations (CEPT) frame, was established in 2001, by combining the European Committee for Telecommunications Regulatory Affairs (ECTRA) and the European Radiocommunications Committee (ERC). The role of ECC is to develop a common European policy in telecommunications technical and regulatory matters, to coordinate between the CEPT members and to generate common European position in various international forums, e.g. ITU and others. In order to achieve these goals effectively, ECC has set up a number of Project Teams (PT). One of them is PT1, the Project Team on "IMT matters". This includes issues of new technologies in IMT (International Mobile Telecommunications, former IMT-2000), e.g. WiMAX, that are considered by relevant ITU Study Groups and Working Parties.

The PT1 tasks are defined in its Terms of Reference; the latest ones are approved by the ECC in March 2008, and cover the period until 2010. Activity of particular interest to IMT specified in the Terms of Reference [Ref 15] is "to Consider the designation and frequency arrangements for spectrum, identified for IMT in the Radio Regulations". Specifically, this is understood as:

- Development of appropriate ECC Deliverables, applying to the use of the new IMT bands (including the issue of border coordination);
- Consideration of the sharing and compatibility issues that supports this work, update existing and develop new appropriate ECC Recommendations and Reports;
- Coordination the work within CEPT and liaison with other relevant bodies, e.g. ITU and ETSI;
- Develop frequency arrangements for new IMT bands

The PT1 has several Sub Working Groups (SWGs) whose work is relevant to this study:

- SWG A, spectrum issues. Currently works on band plans for bands 790 – 962 MHz, 2.3 – 2.4 GHz and 3.4 – 3.8 GHz. The band plans have to consider issues such as duplexer spacing in FDD systems, protection of services in adjacent bands, and legacy channelisation vs. technology expectation (e.g. 8 vs. 5 MHz in UHF band);

- SWG C, sharing and compatibility issues. The SWG is currently working on several sharing issues, of which the most relevant are FDD – TDD sharing in new IMT bands, e.g. 2.5 GHz band, 790 – 862 MHz and cross-border coordination;

- SWG E deals with coordination of CEPT activities in relation to the WP 5D processes for the development of IMT-Advanced. They are currently working on the spectrum related requirements related to IMT-Advanced.

The 29th PT1 meeting was held in Dublin, Ireland, between the 14th and 16th May 2008. The focus of the meeting was in the area of frequency bands for IMT and access technology issues, and it can be seen from the main results of the meeting:

- Agreement was achieved on common views on some procedures and requirements on IMT-Advanced radio interfaces, a contribution to ITU-R WP5D;

- Work has begun with PT SE 42 and ECC TG4on CEPT Report on defining harmonized technical conditions for fixed and mobile networks in the 790 – 862 MHz band (Digital Dividend);

- Work has begun on band plans for the 790 - 862 MHz and 3.4 – 3.8 GHz bands;

- A cross-border coordination Report is being prepared;

- Comments on Draft Report on FDD - TDD coexistence in 2.5 GHz band have been reviewed and the report ahs been prepared for formal adoption.

5.3 ETSI BRAN

European Telecommunications Standards Institute (ETSI) established a standardization project for Broadband Radio Access Networks (BRAN) in 1997 with a task of preparing standards for broadband wireless access (BWA) technology. One of the three technologies BRAN is focusing on is HiperMAN, the technology developed in close cooperation with IEEE 802.16, and with a goal of interoperability with 802.16a.

ETSI BRAN (Broadband Radio Access Networks) is currently working on a number of Working Items (WI). The ones relevant to the FDD – TDD coexistence issues are:

- Preparation of harmonized EN covering essential requirements for BWA system operating in the 2.5 GHz band. The document is EN 302 544-1 to -4, addressing TDD and FDD BS an MS. Draft EN for TDD systems (i.e. WiMAX) are published in May 2008;

- Preparation of harmonized EN covering the essential requirements for BWA BS and MS in the frequency band 3.4 – 3.8 MHz. Draft EN 302 623 was published in May

2008, and work on the equivalent document for BS is ongoing and the draft is expected to be available for downloading after 31/07/08;

- Harmonization of HiperMAN technical specifications with 802.16 Revision 2.

The bulk of current BRAN work is in the area of WiMAX / HiperMAN interoperability (STF 252, 252V and 345).

Regarding the current status of FDD – TDD standardization documents, the key document is TR 125 942 [Ref 1]. Although focused on UTRA version of the FDD and TDD, it still describes the system scenarios with respect to the radio transmission and reception that are relevant to any TDD system involved in TDD – FDD coexistence. The goal of the document is to identify the key coexistence parameters that need to be selected to meet service and implementation requirements.

5.4 WAPECS

The convergence of radio communication services, emergence of new radio access technologies and general fast changes in the area of wireless communications leads to decreased suitability of traditional administrative control of radio spectrum in Europe. The traditional technique of spectrum administration, instead of providing the best economical value to the society, is becoming a limiting factor for the technological innovation and spectrum utilization. This is combined with the increasing requirements for the spectrum between about 400 MHz and 4 GHz, generally seen as most suitable for mobile communications. As a result, the traditional approach to providing the additional spectrum for new, more spectrum demanding services – allocating new chunks of spectrum at higher frequencies – is not feasible any more, and a new approach that will provide more efficient use of the existing spectrum is needed.

In order to address the issue of most suitable spectrum administration, the European Commission (EC) has given the task to its Radio Spectrum Policy Group (RSPG) in 2004 to develop a new spectrum policy on the Wireless Access Platforms for Electronics Communications Services (WAPECS), with an idea to test that policy in the most critical bands. The tasks are defined in [Ref 16] as:

- To define the range of WAPECS platforms and challenges related to the spectrum;

- To define long-term objectives for the regulation of spectrum used by WAPECS platforms;

- To give options for introduction of more flexible and technology neutral spectrum regulation, giving more freedom to the industry to use best platforms and technologies for converged services; and

- To assess a need for transitional period for this new regulatory approach.

The RSPG has replied in November 2004 with a document [Ref 17] that describes the scope, tasks and structure of the RSPG activities in response to the given mandate:

- The scope of platforms was defined as 2G/3G, IMT-2000 evolution and beyond, WiFi, WiMAX, PMR and PAMR, fixed wireless access and digital broadcasting;

- The bands of interest to the technologies above;

- The impact that convergence of service has on spectrum regulation in the long term and adaptation of regulations in order to follow the long-term changes in convergence, and

- Definition of the transition period.

The RSPG has developed a draft opinion that was, after a period of public consultation, published in 2005 [Ref 18]. This document defines WAPECS concept.

Based on the surveyed opinions of the EU member states and the responses to public consultation, the RSPG suggested the following actions:

- Identification of the frequency bands most appropriate to WAPECS concept;

- Identification of the technical and other (e.g. national licensing) constraints in each band;

- Identification of measures for improved authorisation within the member states;

- Definition of the implementation packages.

The first implementation package was expected to produce a first subset of bands over which there is a consensus for WAPECS implementation.

After a workshop held in Brussels in February 2006, the EC gave a mandate to CEPT to develop least restrictive technical conditions for WAPECS [Ref 19]. The bands of interest are:

- 470 – 862 MHz (the Digital Dividend band)

- 900, 1800 MHz and 2 GHz bands (2G / 3G bands);

- 2.5 and 3.5 GHz bands.

As the response to this Mandate, in December 2007 CEPT has produced Report 19. Following a period of public consultation, the report was published in March 2008, [Ref 20].

The report first addresses the issues of general methodology for technical analysis, covering radio network scenarios, systems, and analysis models. The scenarios are fixed, mobile and indoors. The reference systems describe the network scenario (power, coverage, mobility, FDD/TDD etc) and expectations of the future receiver performance, mostly in terms of receiver sensitivity and selectivity. Discussed models for analysis are:

- Traditional model based on interference link budgets;

- Definition of spectrum usage rights based on block edge masks (BEM) this approach (and values defined in the CEPT Report 19 are the basis of discussions in this document in Section 3);

- Model based on PFD masks, that aggregates the PFD at the victim receiver;
- A model similar to the previous one, based on aggregate PSD transmission of interferers;
- A hybrid approach, that tries to combine the best solutions of the other models;
- A Space-Centric Management, that defines maximal EIRP instead of PFD.

The Report continues with the analysis of individual bands considered for WAPECS. The conclusions for bands relevant to this study are:

- **2.5 GHz band:** a set of EIRP BEMs are proposed. It is concluded that 5 MHz of separation is necessary between the FDD and TDD blocks, and these can be used as restricted channels for micro / pico TDD BS deployment. Relaxation of the technical requirements is suggested as a measure the regulator can use to promote cooperation between the operators that may potentially suffer from mutual interference. Coexistence between the geographically separated areas (e.g. different countries) can be based on PFD field strength. It is also suggested that some harmonized standards might need to be updated in line with the defined BEMs. The BEMs are discussed in more detail in Appendix A of this report.
- **3.5 GHz band:** it is decided to retain the rights as described in ECC/REC (04)05 and Annex of ECC/DEC(07)02. These rights consists of BEM with in-block EIRP limits and out-of-block emission power for BS only (there are no additional specific requirements on terminals). A licensing regime that would promote cooperation among the operators though relaxation of technical limitation is suggested. An alternative approach based on EIRP BEM is also suggested for further discussion.
- **470-862 MHz band:** since this band is a subject of another Mandate from EC, under the area of Digital Dividend, the decision was made to wait for the results of this work before detailing any conclusions (e.g. BEM) for this band. The questions of channelisation, guard bands and TDD / FDD blocks within this band should be made in accordance to the Geneva 2006 (GE-06) Plan that harmonizes analogue and digital TV channel usage in ITU Region 1.

The current work in the area of WAPECS is expected to continue through further studies, mainly in definition of least restrictive technical conditions for the 470 – 862 MHz band, but also in other 2G and 3G bands through transposition of the results achieved in the 2.5 GHz band in order to have similar technical conditions in all bands of interest, for the benefit of both equipment manufacturers and the operators. This might be introduced through another EC mandate to CEPT.

6 IMPACT OF FREQUENCY

6.1 INTRODUCTION

The analysis of the factors that affect the feasibility of coexistence between TDD and FDD broadband wireless access systems in the same geographical area given in Section 2.5, and possible interference mitigation techniques discussed in Section 3, are analyzed primarily from the point of their usability in the 2.5 GHz band. Two other candidate bands for deployment of BWA systems are:

- The 3.5 GHz band, specifically frequencies between 3.4 and 3.6 GHz, although some systems might operate in a wider frequency range between 3.3 and 3.8 GHz, and

- The UHF band, that covers the channels currently allocated to broadcast TV that will soon be released through Digital Dividend. The analysis in this section will focus on the upper end of the released band, e.g. the frequencies above about 700 MHz, as it is expected that there will be tendency to release frequencies mostly at the upper end of the band (as shown e.g. in [Ref 30]). However, applicability of key conclusions will also be considered for the 450 - 470 MHz band identified in WRC-07 as a spectrum intended for IMT.

In these two bands, similar issues of coexistence between the TDD and FDD systems will occur, and similar interference techniques can be employed, as in the 2.5 GHz band. The following text contains the analysis of the impact a change of carrier frequency may have on the feasibility of some of the key coexistence factors.

6.2 PATH LOSS

Dependence of the propagation loss for the types of mobile networks that are likely to be deployed in the UHF, 2.5 and 3.5 GHz bands is addressed in ITU-R Recommendation P.1411-3, [Ref 21]. The suggested model for line-of-sight propagation is a two slope model described in Section 2. This model is also used e.g. in the Report [Ref 2]. The model is based on free-space attenuation up to the point where 1st Fresnel zone touches the ground, after which the model assumes the propagation loss exponent of 4. This model is recommended in [Ref 21] for the UHF and SHF (i.e. above 3 GHz) bands. The Recommendation P.1411-3 also indicates that the range within which the propagation exponent of 2 applies is somewhat shorter above 3 GHz, as the road traffic starts affecting the propagation; this effect can be expressed an increased road height.

Due to the proximity of interfering BS and / or MS in the TDD – FDD coexistence scenarios, it is common to assume free space propagation, i.e. the path loss exponent of 2. As the same free-space propagation model is applicable to all candidate bands, the difference in path loss can be expected to come primarily form the different value of the $20 \cdot \log_{10}(.)$ factor. Assuming the free space model, and including a small road height factor in order to accommodate the impact of road traffic at frequencies above 3 GHz,

- The propagation loss at 3.5 GHz can be assumed to be 3 dB more than at 2.5 GHz;

- The loss is 10 dB less at the upper end of the UHF band and 15 dB less at the lower edge, compared to the 2.5 GHz band.

6.3 BUILDING PENETRATION LOSS

Dependence of building penetration on frequency is not straightforward, as the loss depends on the number of other important factors, such as the angle of wave incidence, type of the building material, the size and locations of windows, whether the affected receiver is on the ground floor or on higher floors in the building, etc. Results of the measurements of penetration loss in the frequency range between the 500 MHz and 3 GHz are summarized in ITU-R Recommendation P.679-3, [Ref 22]. This recommendation primarily addresses the penetration loss in satellite communications, but ITU-R suggest that its findings should also be used for short-range radio and LANs, e.g. in P.1411-3, [Ref 21].

The Recommendation P.679-3 suggests that penetration loss increases with frequency by about 1 to 3 dB/GHz in concrete buildings, and shows almost no change with frequency in the glass-walled building. Mean loss, averaged between 0.5 and 3 GHz, was around 12 dB.

Adopting the 2 dB/GHz as the penetration loss dependence on frequency, it can be assumed that:

- The penetration loss in 3.5 GHz band will be 2 dB higher than in the 2.5 GHz band;
- In the UHF band, the building penetration loss will be 4 dB lower than at 2.5 GHz.

6.4 RF CHANNEL FILTERING

Impact of the carrier frequency on RF filter performance can, in first approximation, be seen as inversely proportional. As carrier frequency f_c decreases, filters with the same absolute bandwidth B become easier to realize, as the increase of B/f_c means that filters need to be less selective. Some of the issues where filter selectivity might be important then become:

- The physical size (i.e. volume) of RF filters generally increases as the frequency decrease. At the lowest end of the UHF band, required size of ceramic filters might limit their use to the base stations , while mobile and subscriber stations will more probably use SAW filters;
- For larger relative bandwidths (on lower frequencies) it gets harder to keep the pass-band frequency response flat. This may have less importance with the use of OFDM;
- With an increase in frequency, the secondary effects become more important (i.e. insertion losses generally increase, component tolerances increase, etc) which makes meeting the very tight manufacturing requirements of RF channel filters on higher frequencies is harder in practice than it can be concluded from just frequency scaling;
- Increased LO phase noise also can also contribute to higher ACLR of equipment at higher frequencies.

Taking all factors into account, it can be concluded that similar interference rejection that can be achieved at 2.5 GHz due to RF filtering can be expected at both 3.5 GHz and in UHF band, with the appropriate frequency scaling of the filter frequency response. In other words, RF filters at lower frequencies can be expected to have wider absolute transitional bands, due to the wider relative bandwidth.

6.5 ANTENNAS

Generally speaking, antenna directivity improves with frequency. For the same physical size (in this case, antenna panel height), a base station antenna will have more gain, narrower beam in azimuth, and less back spillage. Higher frequencies generally give more room for control of the isolation between the co-located antennas, as the "near field" shrinks as the frequency increases. Due to this, it can be concluded that achieving high isolation between the co-located antennas becomes more challenging at lower frequencies.

In situations where antenna arrays are being used in order to enable beam forming, spatial separation between the antennas is typically equal to half the wavelength. As the carrier frequency is decreased, spacing between the antennas is proportionally increasing. As a result, practical issues connected with deployment of a large number of antenna elements to enable beam forming at low frequencies can be challenging. This may favor the use of smaller antenna sets (e.g. four or even just two) at the lower end of the UHF band, providing less interference suppression benefit, as opposed to e.g. a set of eight antennas at 3.5 GHz.

Wider antenna elevation beam width on lower frequencies also means there is less relative angular difference (here normalized to the 3 dB beam width) between the angles of arrival of the BS interference and the user MS, leading to less opportunity to discern them in angular terms. It can also be expected that BS at lower frequencies will be deployed in rural areas, having larger cell ranges and giving less opportunity for down-tilt. For this reason, the benefit from increased down-tilt in the UHF band is expected to be less than at 2.5 GHz.

6.6 CONCLUSIONS ON THE IMPACT OF FREQUENCY

6.6.1 THE 3.5 GHZ BAND

Coexistence between the TDD and FDD systems in this band can generally be seen as easier to achieve than in the 2.5 GHz band. Several factors contribute to reduced severity of mutual interference:

- Free space propagation loss is higher by 2.6 dB;
- Increased shadowing and penetration loss caused by buildings and other structures can provides further isolation in cases where there is no direct visibility between the interference source and the victim (e.g. in the case of micro or pico BS deployment, between the two MS, etc).
- In the case of co-located antennas, additional isolation between the antennas may be easier to achieve;
- Larger antenna sets can provide higher beamforming gains.

One of the factors that may make coexistence at higher frequencies more challenging is the need for highly selective RF channel filters at 3.5 GHz.

The issue of technology independent deployment of 3.5 GHz fixed wireless access systems has been a subject of the ECC Report 33, [Ref 31]. The report identifies block edge masks with contiguous assignment of frequency blocks, antenna radiation pattern envelope and limitation to antenna height are seen as main factors in avoiding interference.

As a conclusion, TDD – FDD coexistence is expected to be easier to achieve at 3.5 GHz band than it is in the case for the 2.5 GHz band.

6.6.2 The UHF band

The coexistence issues in this band are opposite to the situation at 3.5 GHz. The main coexistence issue is caused by the lower free space loss, compared to the 2.6 GHz: 9.5 dB less loss at the upper end, at 872 MHz, and almost 15 dB of less free space loss at the lower end of the UHF band, at 470 MHz. This means that the equivalent amount of additional interference isolation has to be achieved through other measures. There is also much less building penetration loss, leading to less shadowing and increased interference between the mobile terminals.

Mainly because of this lower path loss, frequencies below 1 GHz are generally considered to be more appropriate for rural and suburban network deployments; these are characterized by larger cells and higher BS transmit power. This again can be seen as a potential coexistence problem, as it means more interference power into the victim system. Also, results of the statistical analysis given in [Ref 2] indicate that capacity loss in the victim system increases with cell size.

As a conclusion, it may be said that coexistence between the TDD and FDD systems in the UHF band is expected to be significantly harder to achieve than in the 2.5 GHz band. The problems can be particularly challenging close to the lower end of the UHF spectrum. i.e. at 470 MHz, mainly due to the low propagation losses.

7 REFERENCES

[Ref 1] ETSI TR 125 942 V7.0.0, Technical Report, Universal Mobile Telecommunications System (UMTS); Radio Frequency (RF) system scenarios

[Ref 2] "Draft new report on sharing studies in the 2 500-2 690 MHz band between IMT-2000 and fixed broadband wireless access (BWA) systems including nomadic applications in the same geographical area", Draft ITU-R Report M.2113-1, 29th May 2007

[Ref 3] "Draft ECC report on coexistence between mobile systems in the 2.6 GHz frequency band at the FDD/TDD (or TDD/TDD unsynchronised) boundary", Draft ECC Report 119

[Ref 4] "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", Draft CEPT Report 019, CEPT, December 2007.

[Ref 5] "Proposal for a Practical Compatibility and Coexistence Measures Analysis", Roke Manor Research Ltd, Proposal No. 72/08/P/019/R, Issue 2, February 2008.

[Ref 6] "ECC decision of 18th March 2005 on Harmonised Utilisation of Spectrum for IMT-2000/UMTS Systems Operating Within the Band 2500-2690 MHz", ECC/DEC/(05)05, 18/03/2005.

[Ref 7] "Characteristics of broadband wireless access systems operating in the land mobile service for use in sharing studies", ITU Report M.2116, 2007.

[Ref 8] "Generic unwanted emission characteristics of base stations using the terrestrial radio interfaces of IMT-2000", Draft Revision of ITU-R Recommendations M.1580-1, ITU-R Study Group WP8F, 12th September 2007.

[Ref 9] "Generic unwanted emission characteristics of mobile stations using the terrestrial radio interfaces of IMT-2000", Draft Revision of ITU-R Rec. M.1581-1, ITU-R Study Group WP8F, 12th September 2007.

[Ref 10] "RF Power Amplifiers for Wireless Communications", Second Edition, Artech House Microwave Library, Steve Cripps, May 2006.

[Ref 11] "Advanced Techniques in RF Power Amplifier Design", Artech House Microwave Library, Steve Cripps, June 2002.

[Ref 12] "Mitigating techniques to address coexistence between IMT-2000 time division duplex and frequency division duplex radio interface technologies within the frequency range 2 500-2 690 MHz operating in adjacent bands and in the same geographical area", ITU-R Report M.2045 (2004).

[Ref 13] http://www.trilithic.com/RF and Microwave Components

[Ref 14] J.G. Andrews ad al, "Fundamentals of WiMAX", Prentice-Hall, 2007.

[Ref 15] http://www.ero.dk

[Ref 16] Request by the European Commission to the Radio Spectrum Policy Group for an Opinion on a Coordinated EU Spectrum Policy Approach Concerning Wireless Access Platforms for Electronic Communications Services (WAPECS), RSPG04-45, 2004

[Ref 17] RSPG04-57 Rev 2, Wireless Access Platforms for Electronic Communications Services (WAPECS), - Proposed scope, tasks and working structure

[Ref 18] RSPG05-102, Radio Spectrum Policy Group Opinion on Wireless Access Policy for Electronic Communications Services (WAPECS)

[Ref 19] EC Mandate to CEPT to Develop Least Restrictive Technical Conditions for Frequency Bands Addressed in the Context of WAPECS, Brussels, 5 July 2006

[Ref 20] CEPT Report 19, 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, 17/03/2008

[Ref 21] ITU-R P.1411-3, "Propagation Data and Prediction Methods for the Planning of Short-Range Outdoor Radiocommunication Systems and Radio Local Area Networks in the Frequency Range 300 MHz to 100 GHz"

[Ref 22] ITU-R P.679-3, "Propagation Data Required for the Design of Broadcasting-Satellite Systems"

[Ref 23] EC RSC, "Final Draft Commission Decision on the Harmonisation of the 3400-3800 MHz Frequency Band for Terrestrial Systems Capable of Providing Electronic Communications Services in the Community", 14/03/2008.

[Ref 24] "Broadband Data Transmission Systems operating in the 2500 MHz to 2690 MHz frequency band; Part 1: TDD Base Stations", ETSI draft EN 302 544-1.

[Ref 25] "Practical Compatibility and Coexistence Measures Analysis for the WiMAX Forum, Request for Quotation", WIMAX Forum, 4th January, 2008.

[Ref 26] "Service recommendations to support technology neutral allocations, FDD/TDD Coexistence", WiMAX Whitepaper, 10th April 2007.

[Ref 27] "EC Decision on the harmonisation of the 2500-2690MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community", 2008/477/EC June 24th, 2008

[Ref 28] "Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz", ITU-R Rec. P.452-12-2005.

[Ref 29] "Optimum Antenna Downtilt Angles for Macrocellular WCDMA network", Jarno Niemela, Tero Isotalo, and Jukka Lempiainen

[Ref 30] "Reaping the Full Benefits of the Digital Dividend in Europe: a Common Approach to the Use of the Spectrum Released by the Digital Switchover", Communication of the EC, 13/11/2007.

[Ref 31] ECC Report 33, "The Analysis of the Coexistence of Point-To-Multipoint FWS Cells in the 3.4 - 3.8 GHz Band", CEPT, February 2006.

8 GLOSSARY

ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
BEM	Block Edge Mask
BS	Base Station
BW	Bandwidth
BWA	Broadband Wireless Access
CEPT	European Conference of Postal and Telecommunications Administrations
EC	European Commission
ECC	Electronic Communications Committee
ECTRA	European Committee for Telecommunications Regulatory Affairs
EIRP	Effective Isotropic Radiated Power
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
IMT	International Mobile Telecommunications (former IMT-2000)
ITU	International Telecommunication Union
LTE	Long Term Evolution
MIMO	Multiple Input – Multiple Output
MMDS	Multichannel Multipoint Distribution Service
MS	Mobile Station, or Mobile Service
NF	Noise Figure
PA	Power Amplifier
PFD	Power Flux Density
PSD	Power Spectral Density
SISO	Single Input – Single Output
SS	Subscriber Station
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunications System

APPENDIX A BLOCK EDGE MASKS

A.1 INTRODUCTION

Block Edge Masks (BEM) are one possible mechanism to specify the level of interference that transmitters using one duplex technology (e.g. FDD) are allowed to generate in a block of frequencies allocated to a different duplex technology (e.g. TDD). For an FDD system, this means that emissions in the TDD bands have to be compliant to an appropriate FDD BEM; conversely, the TDD emissions in the FDD bands have to meet an appropriate TDD BEM.

The BEM that can be used in the 2.5 GHz band are addressed in the ECC Decision [Ref 27]. The use of BEM acknowledges that the transmit leakage out of the block allocated to the same access technology (i.e. beyond the block boundary) requires tighter emission limits than adjacent channel leakage and spurious band requirements imposed on the equipment within the same duplex technology. The factor that might favour the introduction of BEM is that, once defined, they can then be used as a basis for technology neutrality. The use of BEM does not necessarily presume the radio access technology for the block of frequencies where it may be applied, as long as the interference in the victim block complies with the BEM. Furthermore, any other technology, even one providing a different service, can potentially be deployed in the same band in the future, as long as its out-of-block emission is compliant with the BEM specified for BWA TDD and FDD. It is generally accepted that technology neutrality can provide benefits to the users (through open competition of technologies), operators (through wider choice of available equipment) and economy in general (as an encouragement to technology development).

The approach based on BEM assumes two types of channels:

- Restricted channel, effectively the 1st channel on the TDD side in Figure 25; and
- Unrestricted channel, all other channels in the same figure.

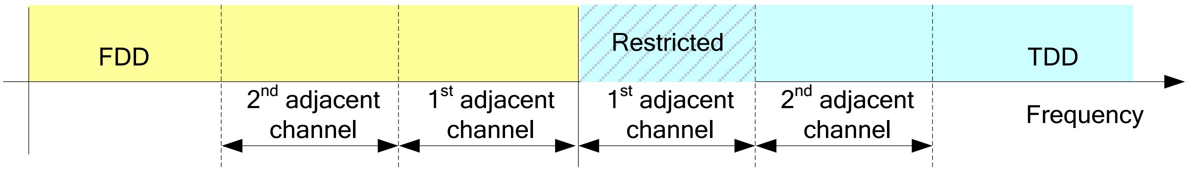


Figure 25 – FDD and TDD channels in mutual interference scenarios

The BEM for an FDD BS operating in a channel adjacent to an TDD-FDD block boundary is shown in Figure 26. The mask defines EIRP and not the transmit power. The values shown in Figure 26 are also translated to 1 MHz measurement bandwidth for easier interpretation; in reality, for frequencies closer to the block boundaries EIRP is defined in 30 kHz measurement bandwidth.

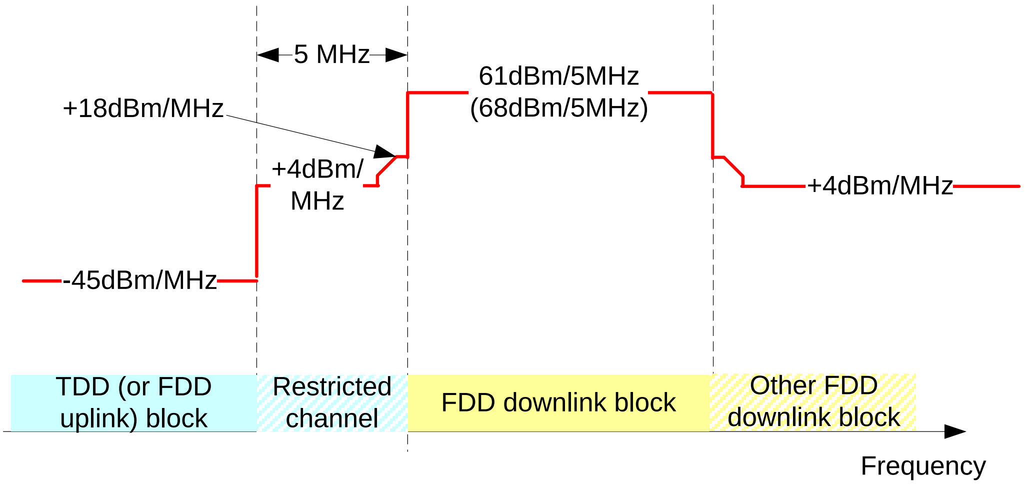


Figure 26 – Unrestricted FDD BS block edge mask

The FDD BEM defined in [Ref 27] and shown in Figure 26 allows 61 dBm of EIRP in 5 MHz, but it is left to individual EU member states to relax the in-block emission to 68 dBm in rural areas, if interference to MS is not significantly increased.

Equivalent block edge mask for TDD BS transmitting in a channel not adjacent to a TDD-FDD boundary is shown in Figure 27. It can be seen that the requirements are tighter in FDD uplink than in the FDD downlink. This reflects the fact that BS-BS interference is the most critical interference scenario for TDD-FDD coexistence.

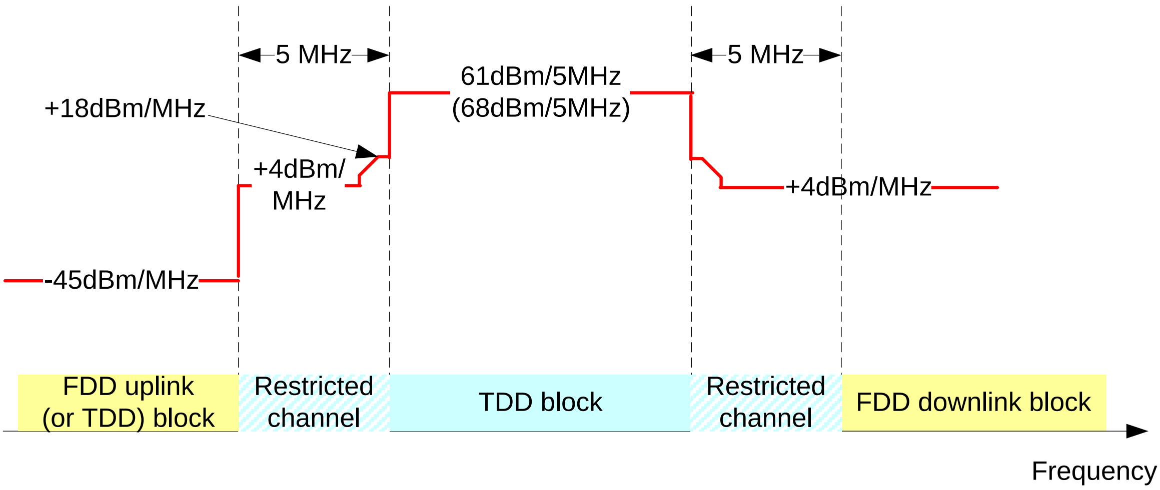


Figure 27 – Unrestricted TDD BS block edge mask

A.2 OPERATION IN UNRESTRICTED CHANNELS

The amount of isolation between the TDD and FDD base stations in unrestricted channels that are compliant with BEM requirements is given in Table 7.

Interference source/victim	FDD MS	FDD BS or TDD
FDD BS	49 dB	98 dB
TDD BS	98 dB	98 dB

Table 7 – Isolation between non-restricted channels in adjacent (TDD and FDD) blocks

It can be seen that compliance to BEM can provide close to 100 dB of isolation between two macro BS in a inter-system interference scenario. It should be noted, however, that these out-of-block emission requirements are significantly (by 33 to 44 dB) tighter than the adjacent channel and spurious band emission requirements defined in the current standards for both UMTS FDD and WiMAX. Therefore, these masks imply additional RF filtering in the BS (as well as careful design and implementation), especially when the equipment operates in the 1st and 2nd adjacent channel to the block boundary.

Tight filtering requirements that result from tight BEM requirements are expected to add to the cost of base stations in the 2.5 GHz band. Therefore, the BEM has to be agreed at the international (e.g. EU) level. It might also become part of the operator's licence conditions; this approach is suggested, e.g. in [Ref 4], Section 3.3. The potential issue with this approach is the fact that the definition of BEM implies that coexistence is to be achieved primarily through improved filtering. The operator should be aware of the tighter filtering requirements imposed by BEM when bidding for the spectrum, as this can mean that infrastructure cost might depend on the proximity of the allocated bands to the block edge.

A.3 OPERATION IN RESTRICTED CHANNELS

Operation of TDD BS in channels adjacent to the block boundary requires additional attention. In this, so-called restricted channel, deployment of macro TDD BS is not possible, as the required level of protection of an adjacent FDD block (e.g. -45 dBm/MHz in Figure 27) cannot be achieved in practice through the filtering means alone. This restricted channel can still be used, however, for micro or pico base stations, where BSs have limited transmit power and where part of the required isolation between it and the victim FDD BS can come from shadowing and the penetration loss of buildings. This additional path loss is assumed for micro and pico BS operating in restricted channels; therefore, the BEM for BSs operating in a restricted channel has a relaxed out-of-block emission mask, as shown in Figure 28.

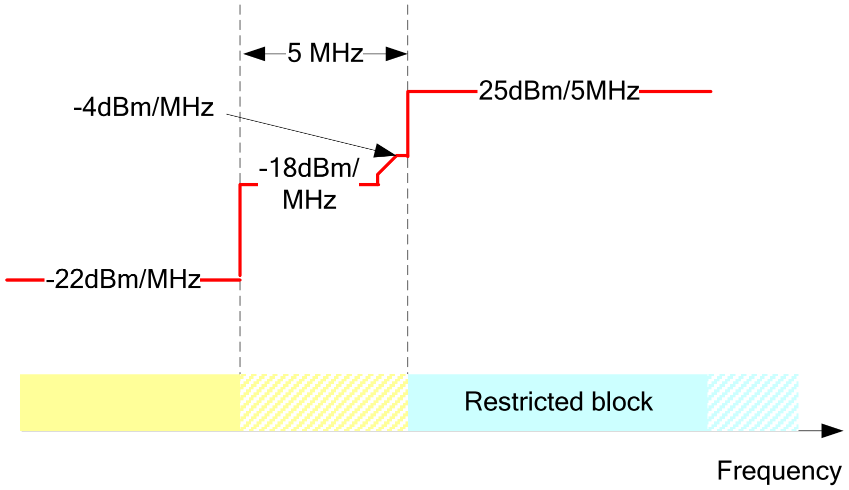


Figure 28 – Restricted TDD BS block emission mask

A.4 BEM FOR MS

A block edge mask similar to the BS masks can also be defined for the MS, and this is being done in CEPT Report 19 [Ref 4], section A.4.5.2. The MS BEM is shown in Figure 29.

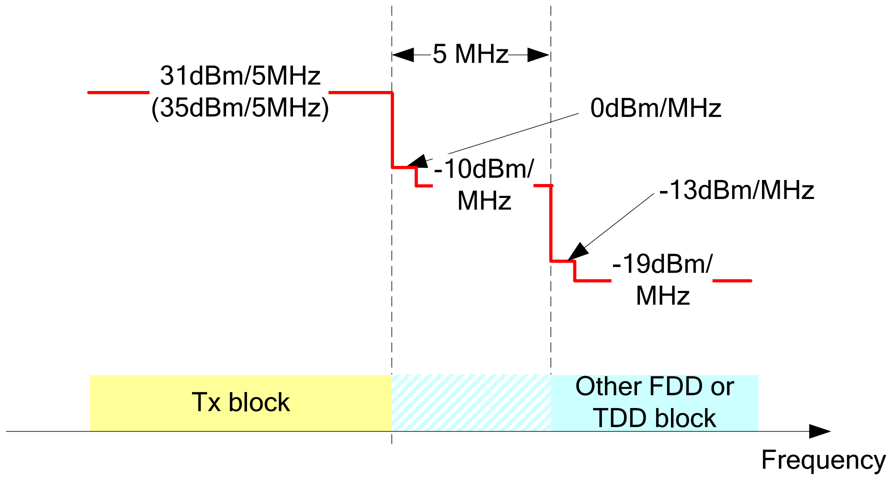


Figure 29 – MS block TRP (EIRP) mask

It is possible to compare the values of BEM for the restricted channel, Figure 29, with the ACLR values for MS defined in e.g. ITU-R M.1581-1 and M.2116, and the values defined by the mask are similar to the requirements that the standards impose on the equipment already.

A.5 Block Edge Mask at 3.5 GHz

Block edge mask for BS operating in the 3.5 GHz band is given in RSC Draft Decision [Ref 23]. The BEM, defined there for base, subscriber and mobile stations (BS, SS and MS) is shown in the following Figure.

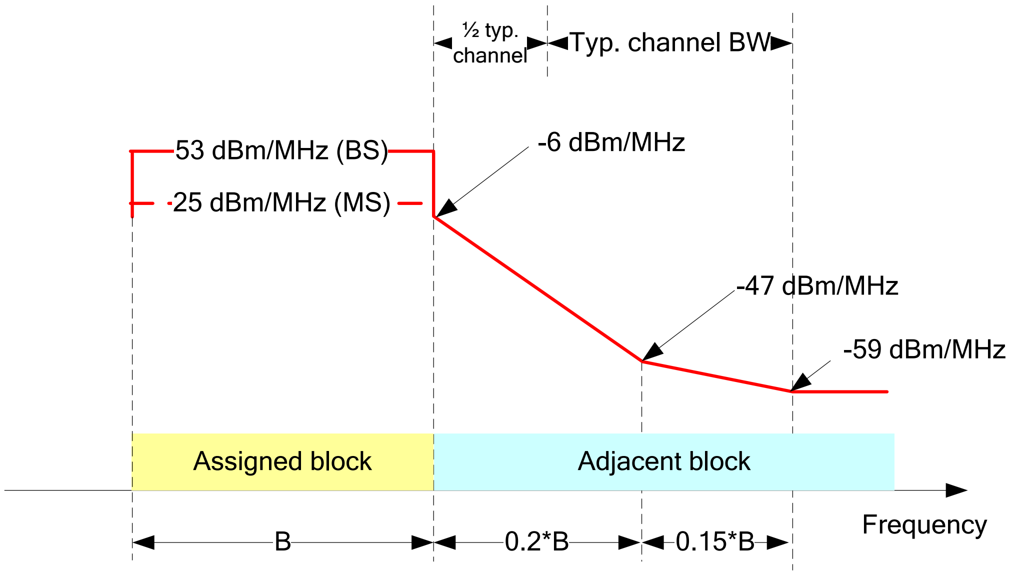


Figure 30 – Block edge mask at 3.5 GHz

The BEM, shown in Figure 30, implies that the transitional band of the RF filter should be contained within 1.5 times the typical channel bandwidth at 3.5 GHz. The limits of emissions in the assigned block are given in terms of maximal EIRP spectral density, while the limits for out of block emissions (i.e. in the adjacent block) are in terms of the transmit output power density.

This page intentionally left blank

Roke Manor Research Ltd
Roke Manor, Romsey
Hampshire, SO51 0ZN, UK

T: +44 (0)1794 833000
F: +44 (0)1794 833433
info@roke.co.uk
www.roke.co.uk

A Siemens company