PA Consulting Group

Flexible use of the 2.6 GHz band in Europe

A study commissioned by the WiMAX Forum

30 April 2008

Communications, media and entertainment

PA

Foreword

About PA Consulting Group

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PA disclaimer

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1 Executive Summary

European regulators will be assigning the commercially significant 2.6 GHz band in 2008 and the following years, taking the ECC Frequency Plan as their starting point

European regulators will be assigning spectrum in the 2.6 GHz band during 2008 and over the coming years. At the time of writing, April 2008, Norway (not part of the EU but within CEPT) has already completed its auctions, Sweden's assignment is imminent and the UK has reached an advanced stage of consultation and planning, with an auction expected later in 2008.

The 2.6 GHz band is of major importance to users and industry participants given the quantity of spectrum available – 190 MHz – and the band's productive blend of effective propagation and high information rate. These features make the band well-suited for wireless broadband communications services such as mobile Internet and wireless multi-media services.

Although over-hyped the first time round when 3G spectrum was auctioned in Europe, these new advanced wireless data services are now showing real commercial potential as the advent of flat-rate data tariffs, improvements to mobile device performance and the availability of content, including user generated content and social networking applications, bring the necessary ingredients for mass market take-up much closer. The Apple iPhone, for example, especially when operating over a WiFi connection, provides a glimpse of the new world of wireless broadband and has generated significant market excitement.

Central to European regulators' plans for the assignment of 2.6 GHz spectrum is the ECC Frequency Plan set down in March 2005 under decision ECC/DEC/(05)05[1] – the ECC is the Electronic Communications Committee within CEPT, the European Conference of Postal and Telecommunications Administrations.

The ECC Frequency Plan (ECC/DEC/(05)05) defines a 50 MHz central sub-band for potential TDD use, with any necessary guard bands to be taken from within the sub-band

As illustrated in the figure below, the ECC Frequency Plan (ECC/DEC/(05)05) defines:

- Two 70 MHz sub-bands for FDD uplink and downlink channels; separated by
- One 50 MHz sub-band between 2570 and 2620 MHz, envisaged for use for TDD-based services or potentially for further FDD downlink capacity (if matching FDD uplink capacity were to be available below the 2.6 GHz band).

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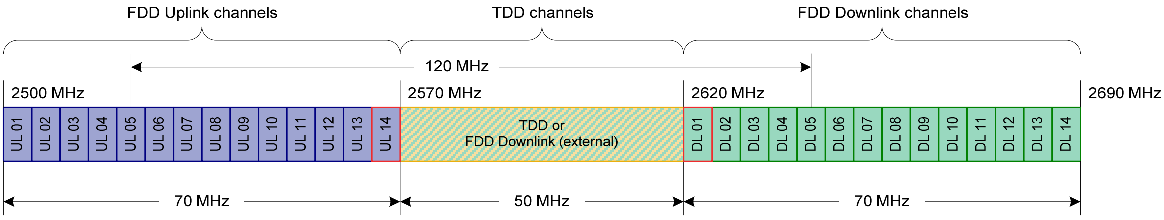
[1] "ECC Decision of 18 March 2005 on harmonised utilisation of spectrum for IMT-2000/UMTS systems operating within the band 2500 – 2690 MHz (ECC/DEC/(05)05)" CEPT, 18/03/2005

Figure 1-1: ECC/DEC/(05)05 band plan



Source: ECC/DEC/(05)/05

The Plan also requires that any necessary guard bands for FDD/ TDD separation should be taken within the central 50 MHz sub-band.

Since 2005, policy and technology developments have shifted towards flexibility including service and technology neutrality as promoted by WAPECS

Since 2005, a number of policy and technology developments have taken place that European regulators now have to take into account when deciding on their approach for the assignment of the 2.6 GHz band, including:

- **Policy developments**: Greater emphasis in policy terms on market-based mechanisms for the assignment of spectrum, in particular service neutrality and technology neutrality – subject to specific band considerations and local circumstances
- **Technology developments**: Development of mature TDD-based technologies, such as the TDD version of WiMAX which is now part of the IMT-2000 family.

In policy terms, there has been a general strengthening of commitment amongst European regulatory communities towards market-based mechanisms for the allocation of spectrum, typically based on auctions. Key elements of this general approach – sometimes referred to under the umbrella term 'flexibility' in contrast to 'harmonisation' – are the concepts of service neutrality and technology neutrality, with spectrum trading also receiving increasing attention.

These concepts are consistent with the WAPECS (Wireless Access Policy for Electronic Communications Services) initiative, developed by the Radio Spectrum Policy group of the European Commission, which promotes the use of spectrum to enable any technology to deliver any service, subject to technical co-existence requirements tailored to each band. CEPT, in its Draft Report 019[2], identifies the 2.6 GHz band as "*suitable from a technical perspective for the introduction of flexibility*".

A very recent development has been the Draft Commission Decision set out in the Radio Spectrum Committee Working Document RSCOM08-02 Final.[3] This Draft Commission Decision on harmonisation of the 2.6 GHz band proposes that the results of the CEPT Report 019 should be implemented without delay, given the increasing demand for broadband communications, with block

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[2] "Draft CEPT Report 019: Draft 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", CEPT December 2007

[3] " Final Draft Commission Decision on the harmonisation of the 2500-2690 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community", RSCOM08-02, Radio Spectrum Committee, 02/04/2008

size assignments of 5 MHz and duplex spacing of 120 MHz for FDD, as well as introducing the concept of Block Edge Masks. The Draft Commission Decision also states that:

"The sub-band 2570 – 2620 MHz can be used by TDD or other usage modes complying with the BEMs in this annex. Outside of the sub-band 2570 – 2620 MHz such usage can be decided at national level and shall be in equal parts in both the upper part of the band starting at 2690 MHz (extending downwards) and the lower part of the band starting at 2570 MHz (extending downwards)."[4]

Assuming this draft decision goes on to be approved, this provides Member States with increased flexibility for spectrum assignments in the 2.6 GHz band.

Whilst this trend towards flexibility appears to be a general one, there are important and recent examples of regulatory bodies placing greater emphasis in specific circumstances on industry policy and social impact considerations with respect to spectrum assignment. For example, the European Commission's backing of DVB-H as a standard for mobile TV in Europe is informed by both industry policy considerations and a consideration of the significant social impact of TV services. Another modification to the principles of flexibility that regulators need to take into account is their local circumstances. For example, purely as a question of geography, issues of cross-border interference are more acute for some European countries than for others.

An important feature of new wireless data service growth is that users are likely to continue to require asymmetric uplink/ downlink bandwidth, as is also the case with fixed Internet links (commonly provided by ADSL). This brings to the fore the potential importance of TDD-based technologies which can use asymmetric uplink / downlink ratios to provide service expansion efficiently.

With regard to technology, development has moved on apace since March 2005. OFDMA and TDD technologies have gained significant vendor backing and we have seen the adoption of the TDD version of WiMAX into the IMT-2000 family. Given the trend towards asymmetric data services in line with the wider take up of mobile Internet and wireless multi-media services, as described above, technologies such as these may offer the potential to bring several different types of benefits to users. These benefits include helping to bring a true wireless broadband experience to market quickly, helping to expand nascent computer-centric and electronic consumer device-centric markets for wireless connectivity and helping to stimulate increased competition within vendor and operator communities.

In this sense, flexibility in the 2.6 GHz band – with respect to service neutrality, technology neutrality and flexible allocation of spectrum for use by either FDD or TDD – is an option that regulators can consider to help stimulate new competition, not only in terms of technology but as a means to introduce new competitors and new business models as well as to stimulate the expansion of existing markets.

Many European regulators are considering 2.6 GHz band flexibility and the optimum allocation of TDD spectrum in relation to the band's 50 MHz central sub-band

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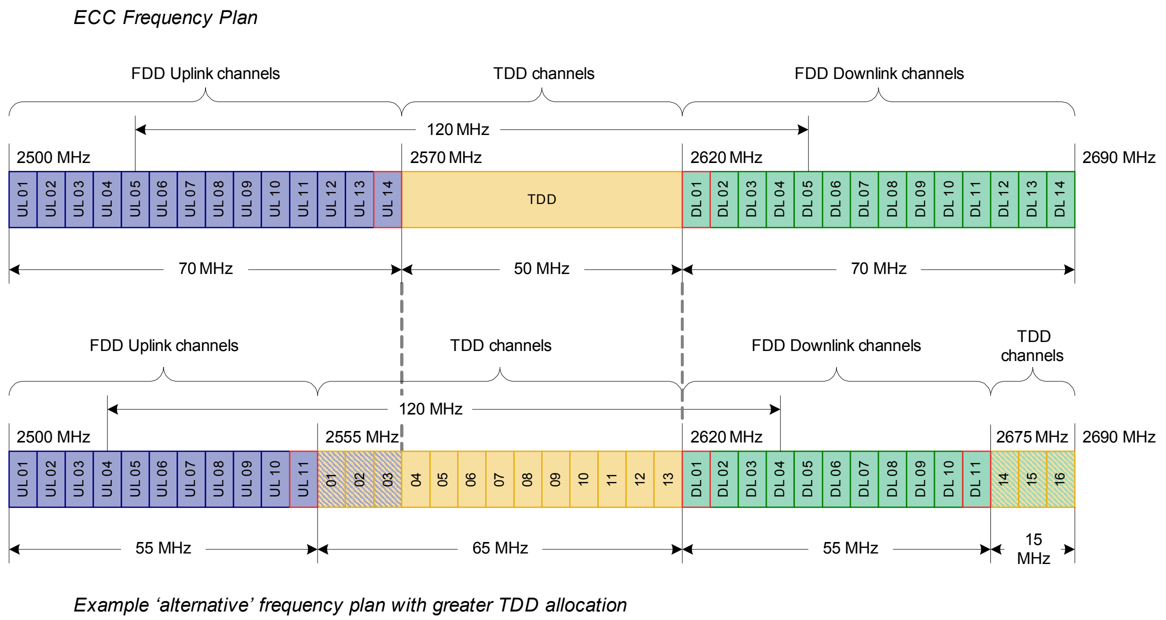
[4] RSCOM08-02, p.5

For the above reasons, many European regulators have plans, at various stages of development, for a flexible approach to the 2.6 GHz band or are giving the issue serious consideration. However, implementation of flexibility in the 2.6 GHz band poses some detailed and challenging questions for European regulators.

A key issue is the quantity of TDD spectrum available in the band to support competitive services and how this spectrum is assigned to the market. Once an allowance is made for guard bands, it is questionable whether two viable TDD-based competitors could be allocated sufficient spectrum from the central 50 MHz sub-band; two TDD-based competitors occupying the central band would have only up to 20 MHz of spectrum each, assuming 40 MHz is available after allowing for two 5 MHz guard bands to separate the FDD and TDD sub-bands (more than 20 MHz per TDD-based operator may be required in order to support competitive headline data rates and to allow for efficient radio network planning).

Regulators, therefore, face the question of whether they can, and should, introduce sufficient further flexibility into the 2.6 GHz allocation process to avoid any sub-optimal outcomes as a result of spectrum packaging decisions prior to auctions. An example of how additional TDD spectrum could be assigned within the 2.6 GHz band is given in Figure 1-2.

Figure 1-2: An example alternative band plan with greater TDD allocation than the ECC Frequency Plan (ECC/DEC/(05)05)



Source: PA analysis, ECC/DEC/(05)/05

The figure shows the way in which additional TDD spectrum might be most sensibly accommodated within the 2.6 GHz band: preserving 120 MHz duplex spacing between corresponding FDD uplink and downlink channels and, potentially, positioned at the upper-most ends of the FDD sub-bands in order to minimise the prospects of interference with out-of-band services (purely for illustration purposes, six additional 5 MHz TDD channels are shown but this number of channels is not significant).

This paper focuses on 'FDD/ TDD flexibility' specifically and addresses the question: Can flexibility work in the 2.6 GHz band?

The question of assignment of an optimal mix of FDD/ TDD spectrum in the 2.6 GHz band has associated questions concerning appropriate spectrum engineering arrangements to define channelisation and deal with interference management.

For clarity in this paper, we use the term '*FDD/ TDD flexibility*' to refer in aggregate to these three key elements:

- **FDD/ TDD split** – the flexible allocation of spectrum within the 2.6 GHz band for use by either FDD or TDD technologies according to market demand
- **Channelisation** – the definition of the nominal channel bandwidth within the assignment process in such a way as to support flexibility and avoid sub-optimal spectrum assignment outcomes
- **Interference management** – an approach to the implementation of guard bands and / or other interference management techniques that supports the flexible allocation of spectrum to multiple services or operators.

Regulators considering the practical implementation of *FDD/ TDD flexibility* in the 2.6 GHz band will ask themselves the question: ***"Can flexibility work?"***

This issue is of interest, of course, not only to regulators but to a wide range of industry participants including service providers and vendors. Against this background the WiMAX Forum® has asked PA Consulting Group to carry out an independent study into the practicality of *FDD/ TDD flexibility* in the 2.6 GHz band in order to add to the body of reference material on the topic and help promote informed debate and decision-making.

PA has researched perceived issues with implementing FDD/ TDD flexibility and developed our own analysis of their potential impact and ease of management

In order to address the question "***Can FDD/ TDD flexibility work in the 2.6 GHz band?***", we have carried out extensive desk research and interviews with a number of European regulators in order to understand the range of opinions on the topic and determine, as a starting point, a comprehensive set of perceived concerns and criticisms relating to the implementation of *FDD/ TDD flexibility* in the band. It is important to stress the word "perceived" as this issue set, derived from our desk and interview research, has been the starting point from which we have then developed our own analysis. This set of perceived issues does not reflect PA's own starting point but rather the 'superset' of perceived issues that we have been able to identify; recognising that industry participants' views of the significance of the issues varies. We have then developed our analysis in two distinct steps:

- **Impact assessment**: Firstly, we have considered the potential impact of each perceived issue across the full community of users in a given jurisdiction (considering home-based and roaming users) in the absence of any attempt to manage the situation – this provides an indication of "what is at stake"
- **Issue management:** Secondly, we have considered how in practice the perceived issues could be managed or mitigated by regulators and other industry participants, taking account of the difficulty of management and whether or not the perceived issue would in fact be resistant, fully or partly, to measures to manage it.

Clearly, the issues of most significance to anyone considering implementing *FDD/ TDD flexibility* are those with a high potential impact and a high degree of challenge for regulators or other industry participants attempting to manage or mitigate these issues.

Findings of our research and analysis

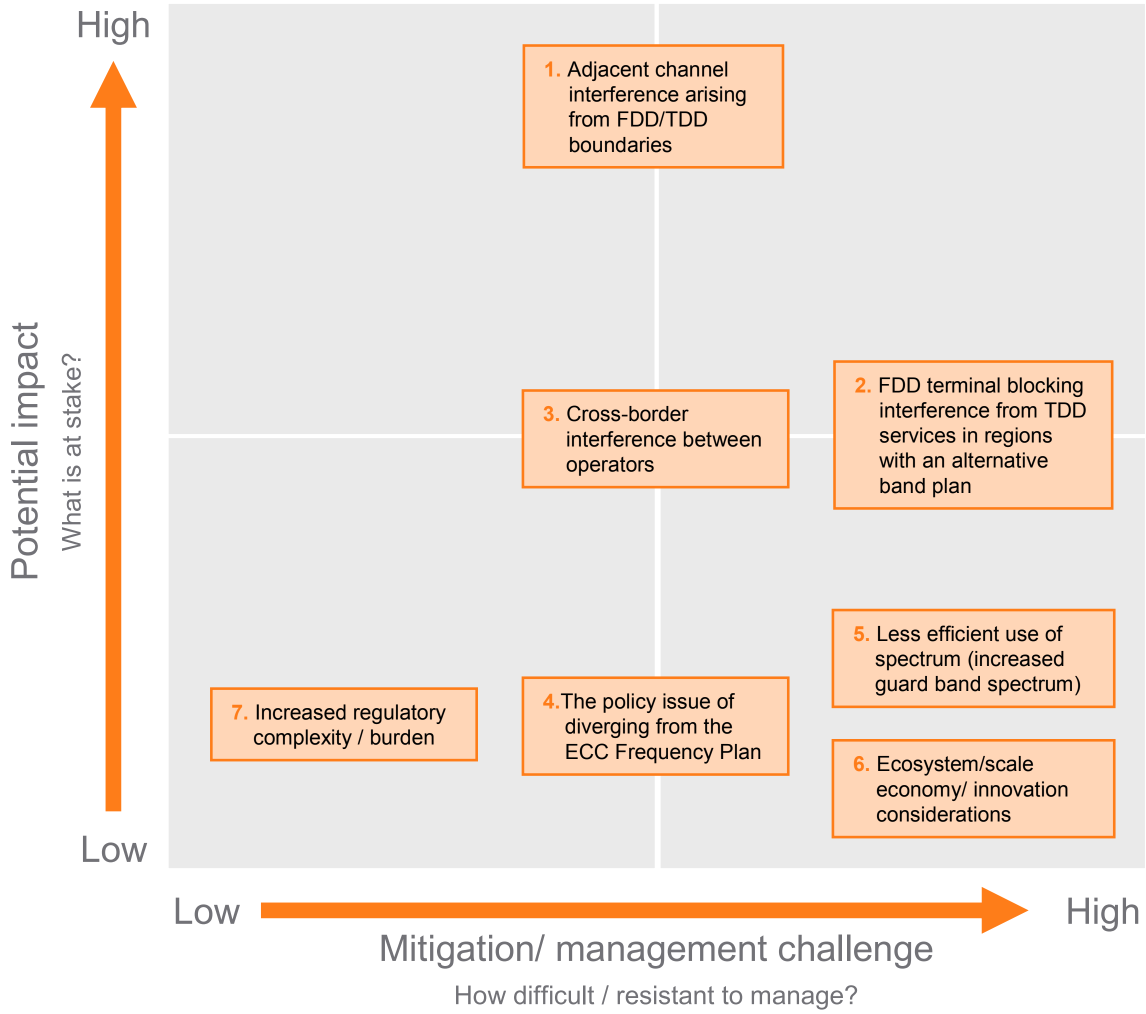
Our research indicates that the perceived issues with FDD/ TDD flexibility fall into three broad categories: interference effects; efficiency, scale and innovation; and regulatory policy

Our research has identified a number of perceived issues falling into three broad categories:

- **Interference issues** – related to: adjacent channel interference potentially resulting from FDD and TDD systems operating either side of the FDD/ TDD spectrum boundary; blocking resulting from the possibility of FDD and TDD systems operating in the same sub-bands; and cross-border interference that could occur when FDD and TDD systems are operating close to a border
- **Efficiency, scale and innovation issues** – related to the potential for market fragmentation and greater unused spectrum allocated to guard bands
- **Regulatory protocol issues** – related to adherence to the international decision-making process and the regulatory burden of implementation of *FDD/ TDD flexibility*.

The figure below maps each of the perceived issues identified in our research against the PA view, based on our own analysis, of the actual potential impact and management challenge in each case.

Figure 1-3: PA's analysis of the actual importance of perceived issues with the implementation of *FDD/ TDD flexibility* in the 2.6 GHz band



Sources: PA analysis, UMTS Forum, WiMAX Forum®, Booz Allen Hamilton, OFTA, PTS, NPT, Ofcom, ECC/ CEPT.

To develop the mapping shown in the figure we have adopted the following approach:

- **Independent views of impact and management challenge:** – we have considered the potential impact and management challenge of each perceived issue separately
- **Three state scale:** – we have rated potential impact and management challenge into three broad levels: (i) 'no/ minimal' impact/ challenge; (ii) 'moderate/ significant' impact/ challenge; and (iii) 'very significant' impact/ challenge (noting that a 'very significant' impact for a small number of users may result in a 'moderate/ significant' impact in overall terms).

Our analysis indicates that only three of the perceived issues with FDD/ TDD flexibility identified in our research are of significant potential impact and management challenge

The most significant of the perceived issues in our view relate to:

- **Adjacent channel interference arising from FDD/ TDD boundaries**

- **FDD terminal blocking interference from TDD services in regions with alternative band plans (to ECC Frequency Plan (ECC/DEC/(05)05))**
- **Cross-border interference between operators.**

We summarise each of these issues in turn below, noting that whilst the remaining four perceived issues identified in the figure above are considered of lesser significance, in accordance with the rating scale described above, their importance may increase depending on local circumstances (these issues are discussed further in the main body of this report):

(1) Adjacent channel interference arising from FDD/ TDD boundaries

Potential impact: ***Without management, there is potential for very significant adjacent channel interference between FDD and TDD systems at the FDD/ TDD spectrum boundary***

The opportunity for very significant interference will be present wherever there are adjacent FDD and TDD sub-bands. Under the ECC Frequency Plan (ECC/DEC/(05)05), there are two boundaries where this can occur. Alternative band plans with a greater proportion of TDD allocation would have at least one more such FDD/ TDD boundary.

The impact when such interference does occur will be experienced by users as reduced Quality of Service (QoS) or increased drop-out rates/ loss of service.

Issue management: ***Guard bands are required to manage adjacent channel interference but their width should be minimised; appropriately specified emission limits, along with a number of specific interference management techniques, can also be used to limit interference in a flexible manner***

The ECC Frequency Plan (ECC/DEC/(05)05) mandates that any guard band spectrum is absorbed by the central 50 MHz sub-band. As discussed above, this may introduce a significant restriction on the number of TDD-based operators that can co-exist in the band and provide viable wideband services.

In terms of guard band size, there is consensus from three independent sources – a report prepared by Mason Communications for Ofcom[5], CEPT Report 019[6] and PA's own modelling work – that 5 MHz guard bands are sufficient.

An alternative approach to a completely empty guard band would be to allow power levels equivalent to picocell deployments in the FDD/ TDD boundary channels – this would be at the expense of reducing, to an extent, the effectiveness of the guard band.

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[5] 2500-2690MHz, 2010-2025MHz and 2290-2302MHz Spectrum Awards Engineering Study, 22 November 2006, Mason Communications Ltd. commissioned by of Ofcom

[6] Draft ECC Report on coexistence between mobile systems in the 2.6GHz frequency band at the FDD/ TDDFDD/ TDD (or TDD/TDD unsynchronised) boundary, Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations

The second activity that regulators need to perform to prevent FDD/ TDD boundary interference whilst maximising spectral utility is to specify appropriately permitted emission limit levels. The most appropriate and most widely adopted approach for this is the Block Edge Mask (BEM) approach.

Regulators may also wish to provide a formal process for intermediation in order to be able to resolve satisfactorily any residual interference occurrences.

Specific interference management techniques that can be used include:

- Locating FDD and TDD base stations in the same geographic location (to minimise occasions when interferer signals could dominate wanted signals)
- Separating base stations vertically or through antenna directivity and appropriate cell channel allocation
- Deploying better receiver front-end filtering, especially in base stations
- Deploying Active Antenna Systems with adaptive steering
- Developing improvements in transmitter / receiver performance.

(2) FDD terminal blocking interference from TDD services in regions with alternative band plans

Potential impact: ***Blocking of FDD terminals by TDD terminals has the potential to cause very significant interference in certain circumstances***

FDD terminal receiver RF front-ends designed with ECC Frequency Plan (ECC/DEC/(05)05) in mind are likely to be open to the entire 2620 – 2690 MHz FDD downlink sub-band, with channel filtering performed at Intermediate Frequency (IF). When used in a non-ECC Frequency Plan (ECC/DEC/(05)05) environment – an 'alternative band plan region' – TDD terminal users on channels falling within this specific range may interfere with FDD terminals. This effect could impact FDD terminals native to an alternative band plan region as well as any FDD terminals roaming into such a region.

An equivalent situation would also arise when an FDD terminal transmits in the FDD uplink sub-band, potentially blocking a TDD terminal.

Issue management: ***A consideration of the statistics involved suggests this problem has a low probability of manifestation and could be addressed by error correction techniques***

We have estimated, taking account of the likely transmission duty cycle for TDD terminals together with the user proximity needed to cause interference, that under typical user distributions TDD to FDD co-sub-band terminal-to-terminal interference is likely to occur for only a very small proportion of time The interference effects are likely to be of little or no practical impact to a typical user when modern error correction (for voice and data traffic) and re-transmission techniques (for data traffic) are considered.

(3) Cross-border interference between operators

Potential impact: ***Without management, cross-border interference issues may lead to degradation or interruption of service in proximity to national borders***

All the interference mechanisms that occur within a region can also occur across a regional border. These are added to by the fact that different frequency plans may be adopted by neighbouring regions, resulting in the overlap of FDD and TDD services across a border. If regions do not co-operate sufficiently, co-channel interference may also occur.

With no interference management techniques applied, the primary cross-border interference mechanisms are terminal-to-terminal interference (in adjacent channels, co-sub-band and co-channel) together with base station-to-base station interference (adjacent and co-channel).

Issue management: ***Both technical solutions and co-operation strategies between operators can be used to manage cross-border interference***

Without management, the base station-to-base station interference mechanism could have a very significant impact in border zones. Fortunately, many of the management approaches relevant to adjacent channel interference are applicable and it is important to note that the overall impact of cross-border interference is generally small as the affected area, adjacent to the border, is generally a small proportion of the total region.

Cross-border terminal-to-terminal interference effects are likely to be of little or no practical impact to users after error correction and re-transmission, given their low probability of occurrence.

Cross-border operator co-operation could ensure that the choice of channel for a TDD service on one side of, and adjacent to, a border is not re-used for an FDD service in a neighbouring cell on the other side of the border.

Another strategy that could be used by operators is to use base stations with lower power to fill coverage gaps adjacent to borders. A related technique is to use directional antennas on macro base stations such that the antenna main lobes point away from borders. Both of these solutions will incur additional costs. Costs due to antenna directivity will be negligible and the cost of using low power base stations is likely to be modest in relation to overall network costs for all but the most extreme border geographies.

Conclusions

Given the maturity of TDD-based technologies, such as the TDD version of WiMAX, there is policy interest across Europe in *FDD/ TDD flexibility* within the 2.6 GHz band (meaning the FDD/ TDD spectrum mix and associated channelisation and interference management considerations). This interest is due to a number of reasons, including:

- **General EC spectrum policy on neutrality:** Consistency with the overall regulatory trend towards the implementation of market-based spectrum assignment approaches, in particular service neutrality and technology neutrality, in accordance with the European Commission's WAPECS concept and consistent with the Draft Commission Decision on the harmonization of the 2.6 GHz band (Radio Spectrum Committee Working Document RSCOM08-02 Final).

- **Specific assignment optimisation for 2.6 GHz:** Avoidance of potentially sub-optimal TDD spectrum assignment outcomes in the 2.6 GHz band due to a rigid 50 MHz central sub-band allocation, which could be (just) too little to support two viable TDD-based competitors
- **Stimulus to competition and innovation:** Capturing opportunities for increased user benefits that may flow from the introduction of TDD-based technologies into the ecosystem (recognising that their orientation towards asymmetric data services is in line with emerging user demand) and from a further stimulus to competition and innovation through the introduction of new service providers and new forms of competition.

Concerning the practicalities of implementing *FDD/ TDD flexibility* in the 2.6 GHz band, our desk and interview research has identified seven perceived issues amongst stakeholders. We have assessed these perceived issues in terms of their potential impact and the extent to which, and how, they can be managed in order to implement *FDD/ TDD flexibility*.

Our conclusion is that whilst a significant number of perceived issues have been raised in the industry concerning the implementation of flexibility in the 2.6 GHz band, there are in fact only three issues that have the potential for significant impact and also present significant challenges in terms of management of the issues in question.

Our analysis suggests that regulators and other industry participants interested in implementing *FDD/ TDD flexibility* should focus primarily on the following three key areas (a further four perceived issues, as set out in the figure above, may be of increased importance depending on local circumstances):

- **Adjacent channel interference arising from FDD/ TDD boundaries**
- **FDD terminal blocking interference from TDD services in regions with alternative band plans (to ECC Frequency Plan (ECC/DEC/(05)05))**
- **Cross-border interference between operators.**

Whilst we consider these issues to be potentially significant in terms of impact and / or management challenge, they are not unfamiliar to industry participants. Achieving *FDD/ TDD flexibility* in the 2.6 GHz band may require adjustments to regulatory processes and the implementation of specific technical approaches to the management of interference but these measures are developments of prior approaches that are familiar to regulators and operators.

Consequently, jurisdictions considering the ECC Frequency Plan (ECC/DEC/(05)05) and the implementation of *FDD/ TDD flexibility* will need to balance the potential benefits available in terms of service innovation and enhanced competition with a thorough assessment of the implementation issues, including those highlighted in this report, as well as other relevant issues and local circumstances.

Depending on specific local circumstances, *FDD/ TDD flexibility* can work. In the final analysis, local circumstances such as the state of incumbent competition and innovation, as well as the complexity associated with the implementation of *FDD/ TDD flexibility* (e.g. cross-border arrangements) are likely to play a significant part in any decision with regard to the implementation of flexibility in the 2.6 GHz band.

2 Introduction

In this section we set out the objectives, target audience, sponsorship and authorship of this paper.

The WiMAX Forum® has commissioned PA Consulting Group to conduct an independent study into the implications of introducing flexibility in the allocation of FDD and TDD spectrum in the 2.6 GHz band in Europe.

The WiMAX Forum® requested PA Consulting Group to carry out a study to enable industry participants to better understand the implications of adopting a more flexible approach to the allocation of spectrum in the 2.6 GHz band, specifically with respect to the spectrum allocations available for FDD and TDD multiple access schemes. The WiMAX Forum® believes that this topic needs greater clarity in order to promote a well-informed debate amongst regulators and other industry participants.

Interest in the 2.6 GHz spectrum band is expected to focus on wireless broadband data services delivering a broadband Internet-like experience over next-generation bearers such as HSPA+, WiMAX and LTE, with voice capacity expansion also being of importance in some markets. Terminals for wireless broadband services will include laptops as well as ultra-mobile entertainment and gaming devices in addition to more conventional mobile phones.

Flexibility is one aspect of a broader debate over the extent to which regulators can use market forces to manage spectrum resources. A number of market mechanisms can be used to facilitate appropriate allocation of spectrum resources, including:

- **Service neutrality** – enabling spectrum owners to use spectrum resources to support any service (e.g. fixed, nomadic and mobile telecommunications as well as other services such as mobile TV)
- **Technology neutrality** – enabling spectrum owners to use any appropriate technology to support its services (e.g. UMTS, WiMAX)
- **Spectrum trading** – enabling industry participants to transfer spectrum without further recourse to regulators (e.g. to correct inappropriate allocations of spectrum following initial allocation and to respond to changes in the market).

In principle, the notions of service neutrality and technology neutrality have gained ground and reached a significant degree of acceptance in Europe. European regulators broadly concur that when there is competition for spectrum resources a market-based allocation approach is the most appropriate. Spectrum trading is receiving increasing interest as an effective method of correcting allocation imbalances that may occur over time. However, the interpretation of service and technology neutrality varies between markets, with regulators taking different views on how it can be implemented in practice. In addition, regulators also consider industry policy and social impact arguments when defining detailed policy for specific spectrum ranges and sometimes consider these imperatives to be of primary importance. For example, the European Commission's backing of DVB-H as a standard for mobile TV in Europe is informed by both industry policy considerations and a consideration of the significant social impact of TV services.

Assigning spectrum in a way that allows some flexibility in the amount of spectrum allocated between FDD and TDD may have a significant impact on operators wishing to deploy TDD-based technologies, such as the TDD version of WiMAX, effectively in the 2.6 GHz band, as well as increasing the possibility for multiple TDD-based operators in the market, which could increase overall efficiency.

In designing their auction processes, European regulators are assessing the most appropriate course of action, taking account of the Frequency Plan defined by the Electronic Communications Committee (ECC) of the Conférence Européene des Administrations de Postes et Télécommunications (CEPT) in decision DEC/(05)05 – referred to as the ECC Frequency Plan (ECC/DEC/(05)05) in this paper – in the context of their local circumstances.

An important part of this decision making process is the question of whether to allow flexibility in the amount and positioning of TDD spectrum within the 2.6 GHz band. This question of assignment of an optimal mix of FDD/ TDD spectrum in the band has related questions concerning spectrum engineering arrangements to define channelisation and deal with interference management appropriately.

Against this background, when we address the question of *FDD/ TDD flexibility* in the context of the 2.6 GHz band in Europe, we are referring specifically to the inter-related concepts in the box below that have bearing on enabling the market to influence the amount of spectrum allocated for FDD and TDD use:

Definition of FDD/ TDD flexibility for the purpose of this paper:

- **FDD/ TDD split** – The flexible allocation of spectrum in the 2.6 GHz band for use by either FDD or TDD technologies, according to market demand
- **Channelisation** – The definition of the nominal channel bandwidth within the assignment process in such a way as to support flexibility and avoid sub-optimal spectrum assignment outcomes
- **Interference management**– An approach to the implementation of guard bands and / or other interference management techniques that supports the allocation of spectrum to multiple services or operators.

This document is aimed at industry participants generally, and National Regulatory Authorities (NRAs) in particular, who are interested in pursuing flexibility within the 2.6 GHz band and wish to understand the implementation considerations

This document is intended as an input to the broader debate concerning flexibility and to be of relevance to all industry participants – particularly regulators considering a flexible approach to spectrum allocation in the 2.6 GHz band.

Regulators considering the implementation of *FDD/ TDD flexibility* will ask themselves the question: *"**Can flexibility work?**"*

This study focuses on this high-level question, applied to three key elements of *FDD/ TDD flexibility* defined above, as follows:

- **FDD/ TDD split** – is an alternative allocation of FDD and TDD spectrum to the ECC Frequency Plan DEC/(05)05 band plan appropriate?

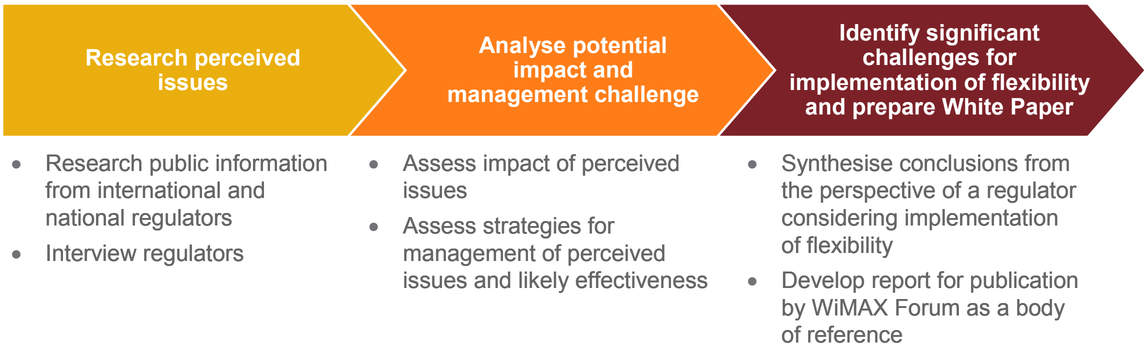
- **Channelisation** – what implications are there for channelisation in order to support flexibility?
- **Interference management** – what implications are there for efficient interference management in the context of flexibility, neutrality and multiple operators?

The primary aim of this paper is to provide objective analysis concerning the practical implementation of *FDD/ TDD flexibility* in the 2.6 GHz band in Europe so that industry participants can better discriminate any important issues from secondary distractions. This issue is of interest, of course, not only to regulators but to a wide range of industry participants including service providers and vendors.

We have sought to identify perceived issues and opinions amongst industry participants concerning FDD/ TDD flexibility in the 2.6 GHz band and to discriminate between any important issues and secondary distractions

We have used a three-step approach to produce this report as set out in Figure 2-1.

Figure 2-1: Report development process



Source: PA analysis

This approach has enabled us to draw on views expressed by different parties from a wide range of backgrounds to establish the perceived issues associated with implementing flexibility in the 2.6 GHz band. We would stress that our starting point has been to research a comprehensive list of perceived issues and then to analyse them objectively in order to make an assessment of their actual potential impact and the extent to which they can be managed.

This report is based on research and analysis carried out in Q1 2008, but also takes account of the important Draft Commission Decision on harmonisation of the 2.6 GHz band (Radio Spectrum Committee RSCOM08-02 2 April 2008).

Our analysis indicates that, in fact, only three of the perceived issues concerning FDD/ TDD flexibility in the 2.6 GHz band are of significant potential impact and management challenge

Our report concludes that whilst a significant number of perceived issues have been raised in the industry concerning the implementation of flexibility in the 2.6 GHz band, there are in fact only three issues that have the potential for significant impact and also present significant challenges in terms of management or mitigation.

As we discuss in more detail in our report, these issues relate to:

- **Adjacent channel interference arising from TDD/ FDD boundaries**
- **FDD terminals blocking interference from TDD services in regions with alternative band plans (to ECC Frequency Plan (ECC/DEC/(05)05))**
- **Cross-border interference between operators**

The remainder of this document sets out our research findings and analysis in more detail, organised as follows:

- **Section 3** … Reviews the status of 2.6 GHz band allocations in Europe and other key reference markets at the time of writing (March 2008) and sets out the regulatory and technical background to the debate about flexibility for the band
- **Section 4** … Sets out why the issue of *FDD/ TDD flexibility* in the 2.6 GHz band is important and of interest to regulators and other industry participants
- **Section 5** … Summarises the perceived issues with practical implementation of *FDD/ TDD flexibility* as identified by our research and provides an overview of our assessment of their actual importance, together with some general assumptions underlying our analysis
- **Section 6** … Sets out a more detailed discussion of our analysis of the potential impact and management challenge associated with each of the perceived issues and provides a summary of the approaches that can be taken to address each issue.

In the appendices, we provide more detailed supporting information and technical background. Appendix A provides further detail concerning the status of 2.6 GHz licensing in Europe and other key reference markets. Appendix B provides supporting technical information concerning common underlying interference mechanisms as a 'primer' for the discussions in Section 6. Appendix C provides further detailed discussion of approaches for the definition of emission specifications for interference management in a technology neutral environment. Finally, appendices D and E provide relevant additional material concerning potential FDD downlink use for the 2570 to 2620 MHz sub-band within the 2.6 GHz band and frequency plan channelisation issues respectively.

3 Background

In this section we set out the key background concerning the 2.6 GHz band in Europe including the CEPT plan for the band as defined in ECC Frequency Plan (ECC/DEC/(05)05), auction experience for the band to date and recent trends towards the introduction of increased flexibility.

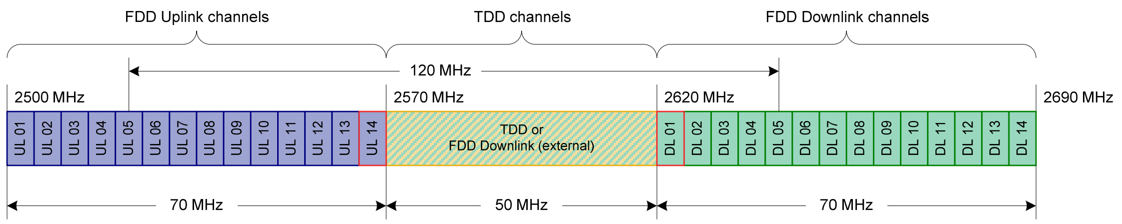
3.1 ECC Frequency Plan (DEC/(05)05) is the starting point for discussion of the 2.6 GHz band

In Europe, the ECC Frequency Plan (ECC/DEC/(05)05) set down by the ECC in March 2005 allocates the 2.6 GHz band to IMT-2000/UMTS services and allows for up to 50 MHz of the band to be allocated to TDD (from 2570 MHz to 2620 MHz)

The 2.6 GHz spectrum band was allocated as the IMT2000/UMTS extension band in 2000. The World Radiocommunications Conference (WRC) 2000 agreed that the 2.6 GHz band should be identified as spectrum for third-generation mobile in addition to the 'core' 2.1 GHz bands[7]. This decision was made as UMTS auctions were either being carried out, or preparations were being made for UMTS auctions.

The Conférence Européene des Administrations de Postes et Télécommunications (CEPT) responded to this decision by designating the 2.6 GHz band for IMT-2000 systems and proposed, in ECC/DEC/(05)05[8], a harmonised frequency plan that reflected the requirements of IMT-2000. Figure 3-1 shows the ECC Frequency Plan (ECC/DEC/(05)05) for the 2.6 GHz band:

Figure 3-1: Channelling arrangements and blocks for IMT-2000/ UMTS in the 2.6 GHz band



Source: ECC/DEC/(05)/05

The ECC Frequency Plan (ECC/DEC/(05)05) is the starting point for discussion of the 2.6 GHz band in Europe. The plan frames channel sizes and the allocation of paired and unpaired spectrum with UMTS in mind and defines the following arrangements with respect to channelisation and interference management:

- **Channelisation**: 2x70 MHz paired spectrum for FDD spectrum separated by 120 MHz, with 5 MHz blocks between 2500-2570 MHz allocated for uplink and 5 MHz blocks between 2620-2690 MHz allocated for

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[7] RR 5.384A of the Radio Regulations applying to the Mobile Service together with Resolutions 223 and 225 and in RR 5.317A together with Resolution 224

[8] ECC/DEC/(02)/06, 15/11/2002

downlink; and a 50 MHz block of unpaired spectrum for either TDD or FDD downlink use, providing the required duplex separation between the paired FDD spectrum blocks.[9]

- **Guard bands**: Any guard bands required to ensure adjacent band compatibility at 2570 MHz and 2620 MHz boundaries are required to be decided on a national basis and taken within the band 2570 – 2620 MHz central sub-band[10]

These key features of the ECC Frequency Plan (ECC/DEC/(05)05) for the 2.6 GHz band define the context in which *FDD/ TDD flexibility*, as defined and discussed in this paper, needs to be considered.

Thus far, ten of the 47 CEPT member administrations have implemented, or indicated their intention to implement, the ECC Frequency Plan (ECC/DEC/(05)05).[11]

3.2 2.6 GHz auction experience to date in Europe and leading global markets

New Zealand, Japan, Singapore and Norway have already allocated 2.6 GHz spectrum, based on different approaches to TDD; other countries in Europe are in advanced stages of planning and are considering at least partial flexibility

In Europe, Norway has already completed its 2.6 GHz auction. Allocation events are scheduled across European Union (EU) states over the coming years, with Sweden being the first Member State to specify its approach and the UK having reached an advanced stage of consultation and planning, with an auction expected later in 2008.

Beyond Europe, 2.6 GHz spectrum has already been allocated in New Zealand, Japan and Singapore. Hong Kong has announced plans to auction the 2.6 GHz band in 2008. Regulators are taking different approaches to flexibility, allowing full or partial flexibility according to their view of the particular circumstances of their local markets, as illustrated in Table 3-1.

[9] ECC/DEC/(05)/05, 18/03/2005

[10] ECC/DEC/(05)/05 Annex 2

[11] European Radiocommunications Office document database, http://www.erodocdb.dk/doks/implement_doc_adm.aspx?docid=2056

Table 3-1: Regulatory approaches to the allocation of 2.6 GHz spectrum around the world

Country	Technology neutral?	Service neutral?	Trading?	Adopted / followed the ECC Frequency Plan (ECC/DEC/(05)05)?	FDD/ TDD flexibility?	Channelisation
Hong Kong	Auction, within IMT-2000 family	Yes	Yes	Partial. Divergence to take account of national satellite mobile band allocation	No, although more TDD spectrum allocated as satellite mobile allocation takes FDD downlink spectrum	5 MHz blocks across all spectrum
Japan	Beauty contest – TDD only	No – mobile only	No	No	No – single blocks of 30 MHz allocated to winning bidders	Two 30 MHz blocks, no channel issue
Norway	Auction, within IMT-2000 family	Yes	Yes	Partial. ECC Frequency Plan (ECC/DEC/(05)05 used as basis with the aim of maintaining 120 MHz duplex separation for FDD	Yes. 60 MHz allocated to either TDD or FDD	FDD dedicated spectrum in 5 MHz blocks, other spectrum allocation in 10 MHz blocks
New Zealand	Yes	Yes	Yes	No	Yes. Spectrum can be used as either TDD or FDD	Block sizes vary – 20, 35 and 45 MHz
Singapore	Yes	Yes	Yes	No. Taking account of cross-border issues. Mostly 12 MHz block size	No. 4 TDD blocks, 4 FDD blocks	20 MHz blocks available for both TDD and FDD
Sweden	Within IMT-2000 family	Yes	Yes	Yes	Partial – able to trade and reassign spectrum to TDD from FDD	In line with ECC Frequency Plan (ECC/DEC/(05)05), 5 MHz FDD blocks with single 50 MHz TDD block

Source: National regulatory authorities

Whilst there is significant consensus on service and technology neutrality, there is no apparent consensus on FDD/ TDD flexibility in terms of FDD/ TDD spectrum split, channelisation and guard bands

Amongst regulators at the vanguard of 2.6 GHz spectrum assignment, there is broad acceptance of technology and service neutrality as appropriate approaches to the implementation of market mechanisms in the allocation of spectrum. However, there is no apparent consensus over the implementation of *FDD/ TDD flexibility* in spectrum allocation as we have defined it in this paper in terms of the spectrum split between FDD/ TDD and associated channelisation and guard band arrangements.

Of the countries that have awarded 2.6 GHz spectrum, Norway and New Zealand used approaches that allowed different degrees of flexibility, whereas Japan and Singapore allocated specific blocks of spectrum to either FDD or TDD.

In Europe, the Norwegian regulator has implemented a flexible approach to FDD/ TDD allocation featuring 60 MHz of spectrum that could have been allocated to either FDD or TDD in addition to the central sub-band, with the caveat of conforming to future CEPT announcements concerning the band. The Swedish regulator has used the ECC Frequency Plan (ECC/DEC/(05)05) as the basis for its auction but has provided for the possibility of a change of use from FDD to TDD following the auction. The UK regulator is currently proposing a highly flexible approach featuring 5 MHz auction bocks in the central sub-band and the ability for the market to influence fully the proportion of TDD and FDD spectrum allocated, whist maintaining the 120 MHz separation between FDD uplink and downlink channels.

The approach to channelisation has also varied. In Japan, New Zealand and Singapore, there was no attempt to allocate spectrum according to demand but bidders were offered different sized blocks. The smallest block size was 20 MHz in New Zealand. Hong Kong, New Zealand and Sweden all decided to use the framework defined by the ECC, but used different allocations:

- In Sweden, the regulator has remained consistent to the frequency plan defined in ECC/DEC/(05)05, with multiple 5 MHz blocks for FDD and one single 50 MHz block for TDD, meaning there can be only one TDD operator
- In Hong Kong, channel sizes for both TDD and FDD are set at 5 MHz, enabling multiple TDD operators to enter the market
- In Norway, whilst spectrum reserved for paired usage has been allocated in 5 MHz blocks, spectrum that could be used for TDD has been allocated in 10 MHz blocks, with the possibility of multiple TDD operators entering the market.

Many European countries will be awarding 2.6 GHz band spectrum over the next one or two years and are now formulating their policies for allocation. Norway has already allocated this spectrum. Sweden and the UK will be amongst the first in the EU to do so and almost all other EU Member States are expected to follow in the coming years.

Further details of regulatory developments concerning the 2.6 GHz band are set out in Appendix A.

3.3 Recent moves towards flexibility in the 2.6 GHz band

EC policy initiatives are moving towards more flexible approaches to spectrum management to realise societal and economic benefits

At the same time that the ECC Frequency Plan (ECC/DEC/(05)05) was being implemented by ten of the CEPT member countries in their national frequency plans, a high-level trend was emerging towards the introduction of elements of flexibility into the assignment and use of spectrum, based on the EU’s Lisbon/ i2010 strategy and responses to it at the supra-national and national levels:

- **The EU Lisbon / i2010 strategy** – The Lisbon strategy and the associated goals of the i2010 initiative
- **Supra-national regulation in response to Lisbon / i2010** – Attempts by supra-national regulatory groups, such as the EC and the Radio Spectrum Committee (RSC), to respond to these policy goals, including the WAPECS initiative (Wireless Access Policy for Electronic Communications Services)
- **Local NRA regulation** – National regulator's responses to international and local policy imperatives.

The European Union's broadly-based Lisbon strategy aims, by 2010, to develop the European economy to become *"the most dynamic and competitive knowledge-based economy in the world with more and better jobs and greater social cohesion, and respect for the environment"*. The strategy focuses on realisation of the knowledge society, completion of internal markets, promotion of competition, the establishment of a favourable business climate, building an adaptable and inclusive labour market and the promotion of win-win environmental economic strategies.[12]

The i2010 strategy recognised that changes would be required in the way policy is implemented:

"Regulation must keep pace with technological and market developments. Therefore, in the 2006 review of the framework, the Commission will thoroughly examine its principles and mode of implementation, especially where bottlenecks are delaying the provision of faster, more innovative and competitive broadband services." [13]

Wireless spectrum, subject to increasing demand driven by new applications, was one of the bottlenecks identified and the i2010 strategy aimed to meet this challenge by developing policy *"to facilitate spectrum access across the EU through market mechanisms.*[14]"

Supra-national standards and regulatory bodies have responded to the challenge of implementing these policy objectives. The European Commission, in COM(2005) 411, promoted the benefits of trading to meet the *"overall aim for management of radio spectrum, i.e. to optimise use of this natural resource for the 'greater good' of society".* The Commission recognised that *"…spectrum markets can improve the efficiency of use of spectrum since industry is better suited than regulators to identify the highest value applications. The artificial scarcity of this good is to be tackled by creating a 'free market' of tradable rights to use particular frequencies according to market demand."*[15]

The WAPECS concept, developed by the Radio Spectrum Policy Group (RSPG) of the European Commission, provides the framework to support the Lisbon strategy and the European Union's policy goals for using spectrum resources to promote competitiveness. WAPECS signals a change in the regulation of spectrum, from 'command and control' to an approach that uses the market to decide the

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[12] "Facing the Challenge: The European Strategy for Growth and Employment," Report from the High Level Group chaired by Wim Kok, November 2004

[13] "i2010 – A European Information Society for Growth and Employment", Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, 01/06/2005

[14] "i2010 – A European Information Society for Growth and Employment", Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, 01/06/2005

[15] "A Forward-Looking Radio Spectrum Policy for the European Union: Second Annual Report", Communication from the Commission to the Council and European Parliament, COM (2005) 411

most appropriate usage. This approach requires removal of technology and usage constraints, and enables spectrum to migrate towards applications that place the highest value on its usage. At the same time, WAPECS addresses co-existence between different technologies as far as possible. CEPT regards the 2.6 GHz band as "*suitable from a technical perspective for the introduction of flexibility.*"[16]

The WAPECS concept promotes the use of spectrum to enable any technology to deliver all services, subject to technical co-existence requirements tailored to each band, and is defined as:

"… a framework for the provision of electronic communications services within a set of frequency bands to be identified and agreed between European Union Member States in which a range of electronic communications networks and electronic communications services may be offered on a technology and service neutral basis, provided that certain technical requirements to avoid interference are met, to ensure the effective and efficient use of the spectrum, and the authorisation conditions do not distort competition."[17]

Technology and service neutrality, as emphasised within the WAPECS initiative, are components of the same drive to use market mechanisms. The RSPG established the principles of technology and service neutrality as the most appropriate way for regulators to assign spectrum but, at the same time, recognised that there may be technical limits to flexibility:

"For each WAPECS frequency band, provided that the associated electronic communications network complies with the relevant spectrum technical requirements, technological neutrality and flexibility in future use of the spectrum should be ensured."[18]

The European Commission has proposed amendments to EC Directive 2002/21 on a common regulatory framework for electronic communications networks and services that reflect the WAPECS concept.[19] The proposal reflected the desire for a *"more flexible approach"* to spectrum management *"to exploit the economic potential and realise the societal and economic benefits of improved spectrum usage."*[20] This is reflected in the promotion of increased flexibility in spectrum management through:

- **Technology neutrality** – allowing *"technology- and service-neutral authorisations to let spectrum users choose the best technologies and services to apply in a frequency band"*[21]
- **Spectrum trading** – *"allowing spectrum users to freely transfer or lease their usage rights to third parties, which would allow spectrum valuation by the market."*[22]

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[16] CEPT "Draft report 019" p.7

[17] "Opinion on Wireless Access Policy for Electronic Communications Networks (WAPECS)", Radio Spectrum Policy Group, 23/11/2005, p.2

[18] "Opinion on WAPECS", RSPG, 23/11/2005, p.14

[19] "Proposal for a Directive of the European Parliament and of the Council amending Directives 2002/21/EC on a common regulatory framework for electronic communications networks and services, 2002/19/EC on access to, and interconnection of, electronic communications networks and services, and 2002/20/EC on the authorisation of electronic communications networks and services", European Commission, COM(2007) 697, 13/11/2007

[20] COM(2007) 697, p. 6

[21] COM(2007) 697, p. 17

With regard to local NRA implementation of policy, NRAs, of course, define local policy in the light of changing policy at a European level but also with regard to local circumstances. The structure of the Norwegian auction, featuring 60 MHz of spectrum that could have been allocated to either FDD or TDD in addition to the central 50 MHz sub-band defined in ECC/DEC(05)/05 reflects local imperatives in the implementation of frameworks established at supra-national levels. This approach reflected its desire to tailor the spectrum allocation to its local market circumstances.[23]

This requirement to reflect local circumstances, and the possibilities for implementing flexibility opened up by CEPT Report 019, is reflected in the Commission's Draft Decision RSCOM08-02. The Decision proposes that EC regulators in Member States should implement the findings of CEPT Report 019, and states that:

"The sub-band 2570 – 2620 MHz can be used by TDD or other usage modes complying with the BEMs in this annex. Outside of the sub-band 2570 – 2620 MHz such usage can be decided at national level and shall be in equal parts in both the upper part of the band starting at 2690 MHz (extending downwards) and the lower part of the band starting at 2570 MHz (extending downwards)."[24]

At the time of writing this Commission Decision remains draft. But assuming it goes on to be approved, as we have done in the drafting of this report, its implications are significant, supporting further flexibility in the assignment of spectrum in the 2.6 GHz band.

In parallel with the regulatory decision-making process for the 2.6 GHz band, and the more general EU policy initiatives towards greater utilisation of market mechanisms, there have been significant changes in the market position of TDD-based technologies, such as the TDD version of WiMAX.

Technology development is generating interest in an alternative/ flexible interpretation to the ECC Frequency Plan (ECC/DEC/(05)05)

The ITU developed IMT-2000 to harmonize 3G mobile systems, prevent fragmentation and increase opportunities for worldwide interoperability. IMT-2000, as defined by ITU Rec. M.1457-6, originally supported three different access technologies – FDMA, TDMA, and CDMA – and five radio interfaces. The Wideband Code Division Multiple Access (WCDMA) air interface, used to support UMTS and adopted across Europe, was central to the development of the ECC Frequency Plan (ECC/DEC/(05)05) for the 2.6 GHz band, with the majority of spectrum consequently being allocated to FDD in 5 MHz bands, separating by 50 MHz reserved for either FDD downlink or TDD.

In recent years, however, there has been significant technology innovation related to radio interfaces for wideband services. WiMAX, for example, has emerged as a viable technology and is now incorporated into the IMT-2000 family alongside more established technologies such as W-CDMA – WRC-07 saw WiMAX technology included in the IMT-2000 family as the sixth technology standard[25].

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[22] COM(2007) 697, p. 18

[23] "Summary of answers to public consultation and updated proposals on technical conditions for the bands 2500-2690 MHz / 2010-2025 MHz", NPT

[24] RSCOM08-02, p.5

[25] Recommendation ITU-RM.1457

WiMAX uses an air interface based on Orthogonal Frequency-Division Multiple Access (OFDMA) technology, in common with 3GPP's Long Term Evolution (LTE) technology, the successor to UMTS.

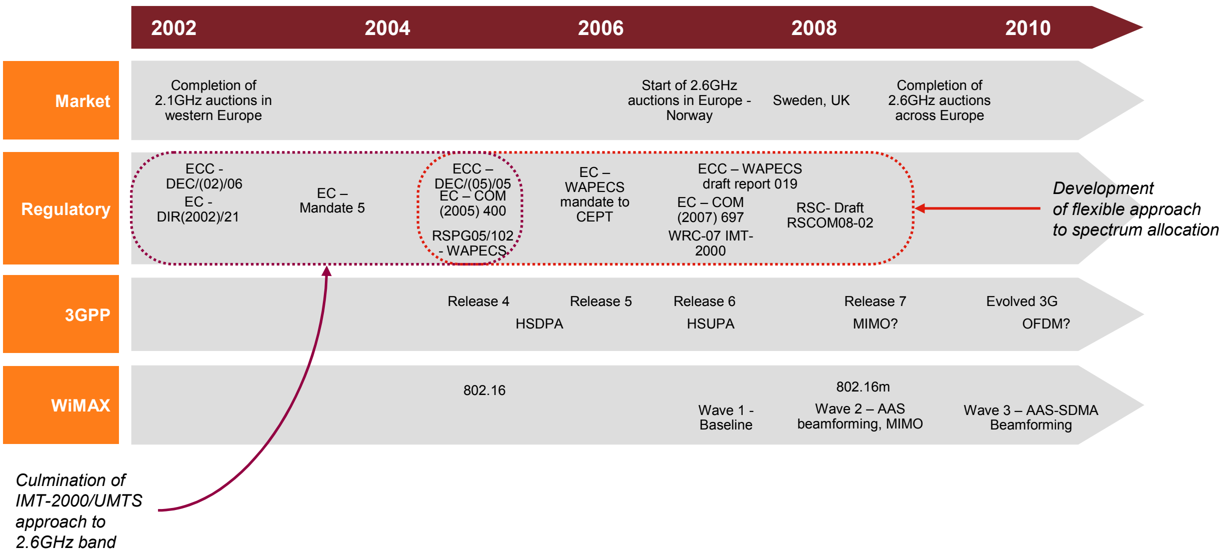
WiMAX has been taken-up for manufacture and implementation by vendors and operators around the world, using TDD access technology to support service, initially for fixed access. The development of IEEE STD 802.16.e for mobile communications extends this capability into mobile services. WiMAX operators are therefore another source of demand for spectrum, and are looking for TDD-compatible spectrum allocations. The inclusion of WiMAX into IMT-2000 potentially represents a greater commercial opportunity for TDD allocations.

The question arises as to whether the detailed implementation of regulatory policy, expressed through ECC/DEC/(05)05, is now out of step with higher order policy intentions

Regulatory frameworks reflect the time in which they are developed. ECC Frequency Plan (ECC/DEC/(05)05) was defined at the culmination of a period of regulatory development in which the 2.6 GHz band was allocated as the extension band for UMTS.

This decision was also made at the cusp of a change from 'command and control' to market-driven approaches to spectrum assignment. Figure 3-2 below illustrates that the conclusion of the ECC/DEC/(05)05 expression of detailed policy occurred at the same time as the WAPECS policy initiative began to explore flexibility more fully and the WiMAX technical standard was being developed.

Figure 3-2: Timeline for development of approach to 2.6 GHz spectrum



Source: PA Consulting

As a consequence, several years on, the question arises as to how ECC/DEC/(05)05 should best be interpreted. Indeed, it is a normal part of the European regulatory process for such decisions to be reviewed from time to time. The ECC governance model allows for review of decisions every three years:

"Each Decision shall be reviewed every three years…to determine the extent of its implementation and the take-up of any frequency bands designated in the Decision, taking account of an initial assessment made by the Office, and any other relevant information. As a consequence of this review the Plenary shall decide whether to maintain, revise or withdraw the Decision."[26]

The frequency plan defined in ECC/DEC/(05)05 has been included in the frequency allocation tables of ten European countries thus far. Implementation is, therefore, far from complete and the regulatory landscape has changed considerably.

In summary, 2.6 GHz spectrum will be assigned across Europe from 2008 and over the following few years. Those nations at the vanguard of assignment of this spectrum in Europe, such as Norway, Sweden and the UK, have sought to address *FDD/ TDD flexibility*, although they have approached the issue in different ways. Given the policy trend towards service and technology neutrality (as emphasised within the WAPECS initiative and the Commission's Draft Decision RSCOM08-02) and the increased maturity of TDD-based technologies (such as the TDD version of WiMAX) three years after the finalisation of the ECC Frequency Plan (ECC/DEC/(05)05), national regulators are considering how best to interpret the plan within the context of overall European regulatory policy frameworks and their own specific local circumstances.

It is against this background that this paper seeks to add to the informed debate concerning the practicality of *FDD/ TDD flexibility* within the 2.6 GHz band. Before addressing the practicalities of the implementation of *FDD/ TDD flexibility*, the next chapter discusses the importance of flexibility in the 2.6 GHz band and why there is interest in arrangements for the band amongst national regulators and other stakeholders.

[26] "Rules of Procedure for the Electronic Communications Committee (and its subordinate entities), Edition 6", CEPT, 21/12/2007, p.11

4 The importance of flexibility in the 2.6 GHz band

In this section we consider why the issue of flexibility is of interest to industry participants and regulators in particular.

In the broader picture, there is uncertainty over the merits of harmonisation versus market-led flexibility for spectrum allocation in specific bands

Flexibility, in broader terms as well as with respect to the specific issues of *FDD/ TDD flexibility* in the 2.6 GHz band as defined in this paper, is a significant issue. There are a number of studies with contrasting positions that examine the benefits and drawbacks of harmonisation in contrast to more market-led stances. One study has suggested that moves away from harmonisation generally (taken as defined technical conditions, including spectrum, band plan and technology, at a global and regional level) could cause a loss of consumer surplus across all spectrum in Western Europe over a 15 year period of €244 billion.[27] An alternative view indicates that the net gain in consumer surplus to the European economy of implementing greater involvement of market mechanisms in the allocation of spectrum could be as much as €8-9 billion a year.[28] These widely differing views reflect the uncertainty and lack of consensus over fundamental approaches to spectrum allocation, of which *FDD/ TDD flexibility* in the 2.6 GHz band is one facet.

This uncertainty is further exacerbated by the accelerating rate of technological change. New candidate technologies for the use of spectrum could lead to step-changes in innovation and challenge the wisdom of reserving spectrum for the IMT-2000 family exclusively. However, the established framework, with common international allocations, could be argued to allow core technologies the time and space to flourish commercially and support international coordination, including roaming.

The 2.6 GHz band is important in terms of social and economic impact and the issue of flexibility, in turn, has significant impact on efficient usage of the band

Allocation of spectrum in the 2.6 GHz band is of major significance to users and industry participants given the quantity of spectrum available and its appropriateness for mobility and wireless broadband services. The 2.6 GHz band is significant in terms of its economic value and, as a corollary, its societal impact. Commercial interest in this band reflects its productive blend of attractive propagation characteristics for wireless applications, high information rate to accommodate broadband services

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[27] "Thriving in Harmony – Frequency harmonisation: The better choice," UMTS Forum (Booz Allen Hamilton, November 2006. Consumer surplus is defined as "the difference between the price consumers are willing to pay (or reservation price) and the actual price paid. If a consumer is willing to pay more than the actual price, their benefit in a transaction is how much they saved." p.18

[28] "Study on conditions and options in introducing secondary trading of radio spectrum in the European Community," p. 222, Analysys/ .econ, May 2004

and the size of the band available. The attractiveness of the spectrum has been a catalyst for technology developments that seek to exploit the value of the spectrum.

The issue of flexible allocation within the band is, in turn, of importance given both the need to:

- Allow for the optimal matching of technologies to the band in terms of the FDD/ TDD mix
- Avoid, as far as possible, sub-optimal outcomes as a result of spectrum packaging design; for example, by allowing insufficient spectrum for TDD-based competition (e.g. two viable TDD-based operators) by perhaps only a small margin of spectrum.

Wireless applications beyond voice and devices beyond the traditional handset now finally seem set to make a mass market impact for a new generation of users

Take-up of mobile data services in the wake of 3G licensing has been behind industry participant's expectations. Voice is still the 'killer app' for most wireless service providers, with SMS accounting for the majority of current mobile data revenues.

However, there are now indications of a shift in user expectations and understanding of non-voice services. This has occurred as wireless network operators have begun to price mobile data services, such as mobile Internet access and email, at a level and in a way that begins to enable mass market adoption. This is comparable with the shift in adoption of fixed home broadband that accompanied moves to higher data rates, flat-rate pricing and always on access.

Operators around Europe are beginning to see significant demand for wireless Internet access services, using a data card or USB modem, encouraged by flat-rate price plans. These services are supported by the increasing data rates that operators are now achieving from their networks following HSDPA enhancements. Where HSDPA is available, users are now experiencing something approaching the service speeds they expect from their home or office broadband services. These enhancements, and the higher speeds supported by technologies such as WiMAX and LTE over time, will allow wireless services to support an increasing variety and complexity of services.

The 2.6 GHz band, originally designated as an IMT-2000/UMTS spectrum band[29], will help provide the additional spectrum resources required to support these new services, including mobile Internet and email as well as mobile video, gaming and other interactive services .

An important feature of new wireless data service growth is that users are likely to continue to require asymmetric uplink / downlink bandwidth, as is also the case with fixed Internet links, commonly provided by ADSL. This brings to the fore the potential importance of TDD-based technologies which can use asymmetric uplink / downlink ratios to provide service expansion efficiently.

Increasing uptake of mobile data services is also likely to be driven by the changing demographics of wireless service users. The next generation of users, children and teenagers who have grown up with

[29] DEC/(02)06, 15/11/2002

fixed broadband access, are likely to expect the same type of experience on their mobile devices with an always-on mobile device playing an increasingly important and integrated part in their lives.

In addition, the expectation that for the majority a wireless connection will still be offered through a traditional handset will be challenged. Whereas mobile handsets have collected functions over time – such as camera, time-piece, MP3 player – an increasing array of other devices will become connected to networks and able to support communications. The integration of broadband wireless access chipsets into almost all laptop computers, for example, would create demand for spectrum from a whole new population of devices. This could extend to ultra-mobile computers and other consumer electronic devices such as MP3 players, gaming consoles and cameras.

The increasing significance of mobile data services combined with the increasing uncertainty in market development, in terms of user behaviour, device development and the proliferation of new services, accentuates interest in adopting flexibility as a further measure to allow influence of market mechanisms in the allocation of 2.6 GHz spectrum.

FDD/ TDD flexibility in the 2.6 GHz band is an option that NRAs can consider to help stimulate competition in their local markets

Flexibility in the 2.6 GHz band could be beneficial in terms of stimulus to competition in three main ways.

Firstly, flexibility could enable the introduction of technologies with alternative and / or increased capabilities into the market more quickly. TDD technologies, such as the TDD version of WiMAX, may be able to offer higher data rate services and/ or alternative value propositions in terms of user experience in comparison to the 3GPP-based technologies such as HSDPA and HSUPA that are being implemented over the next 2-3 years. LTE, the 3GPP successor technology to HSDPA, is likely to have broadly similar capabilities to WiMAX, though there could be difference in capabilities, subtle or otherwise, that provide a platform for greater choice for users.

Secondly, flexibility could enable the introduction of new forms of competitors into the market operating different business models to incumbent providers and with different approaches to revenue generation and customer service.

Whether or not these benefits can be realised in practice is likely to depend in large part on the local circumstances of specific national and regional markets, including factors such as the current status of competition and geo-demographic factors, such as population concentrations and cross-border co-ordination. For these reasons, NRAs will consider carefully the issue of flexibility in the context of national and regional licensing events.

Third, spectrum auctions and trading options expose spectrum owners to the true opportunity cost of the spectrum they are occupying every day. This greater understanding of the value of the resource provides an additional incentive to make the most appropriate use of the spectrum or sell it to someone who can. This is not a direct result of flexibility – indeed trading can be used in markets with a single technology option. But where multiple technologies have access to the market, and flexibility in spectrum allocation reduces barriers to entry by enabling the consolidation of spectrum into contiguous blocks, there is additional opportunity cost pressure placed on providers to ensure they maximise the efficient use of spectrum.

This pressure manifests itself across all participants in the wireless broadband value chain, from developers and manufacturers to operators and service providers that make use of the spectrum, and the applications that consumers and businesses use. The spectrum trading process promotes innovation and efficiency, increasing the rapidity of the investment cycle and demand for new and improved technologies.

Some industry participants argue that the benefits of harmonisation outweigh the benefits attainable from flexibility within the 2.6 GHz band whilst others argue that in the more dynamic and complex world of modern wireless service markets the increased input from market mechanisms that flexibility enables is of greater importance.

The remainder of this report addresses the practicalities of implementing flexibility – specifically *FDD/ TDD flexibility* (meaning the FDD/ TDD spectrum mix and associated channelisation and interference management considerations as defined in this report) – within the 2.6 GHz band, addressing the question from the perspective of a national regulatory authority considering adopting this approach.

5 Overview of perceived issues relating to the implementation of flexibility in the 2.6 GHz band

In this section we discuss the practicalities of implementing *FDD/ TDD flexibility* in the 2.6 GHz band. To give the discussion a clear focus, we have taken the perspective of a National Regulatory Authority analysing the roadmap for implementation of *FDD/ TDD flexibility*. Our aim is that by taking this perspective the discussion will, in fact, be interesting and useful for a wide range of industry participants.

5.1 Identification of perceived issues with the implementation of flexibility

Taking the perspective of a NRA considering FDD/ TDD flexibility, our research has identified seven perceived issues associated with implementation – these relate to three groups: interference effects; efficiency, scale and innovation; and regulatory protocols

As highlighted in the previous section, the 2.6 GHz band is important in terms of societal and economic impact and some NRAs are actively seeking to implement *FDD/ TDD flexibility* as part of a broader range of market mechanisms for spectrum allocation.

In order to assess the implementation challenge for flexibility, we have carried out extensive desk research and interviews with a number of European regulators in order to develop, as our starting point, a comprehensive list of perceived issues with the implementation of flexibility within the 2.6 GHz band. It is important to emphasise the word 'perceived' as this issue set, derived from our research, has been the starting point from which we have then developed our own analysis. This set of perceived issues does not reflect PA's own starting point but rather the 'superset' of perceived issues that we have been able to identify; recognising that industry participants' views of the significance of the issues varies. Further steps in our analysis have addressed the extent to which these perceived issues are in reality of significance and whether, and how, they can be managed.

Table 5-1 below sets out the perceived issues we have identified through our research, organised according to the following broad categories:

- **Interference issues** – in the three distinct operational scenarios:
  - (i) when FDD and TDD systems are operating either side of the FDD/ TDD boundary in a frequency plan
  - (ii) when FDD and TDD systems are operating within the same sub-band; and
  - (iii) when FDD and TDD systems are operating adjacent to a regional border

- **Efficiency, scale and innovation issues** – related to market fragmentation and spectrum allocated to guard bands
- **Regulatory protocol issues** – related to the international decision-making process and the burden of regulatory implementation.

Table 5-1: Perceived Issues with *FDD/ TDD flexibility* implementation in the 2.6 GHz band

Category	Perceived issue	Opinion expressed (from research)
Interference	Adjacent channel interference arising from FDD/ TDD boundaries	FDD/ TDD adjacent channel interference could occur between base stations and handsets. This has the potential to affect the service offered to users.
	Cross-border interference between operators	The adoption of differing band plans between regions may complicate the management of interference issues across regional borders.
	FDD terminals may be subject to blocking interference from TDD services in regions with an alternative band plan	In alternative band plan regions, it is likely that TDD frequency allocations would be within the ECC Frequency Plan (ECC/DEC/(05)05) FDD downlink sub-band. TDD equipment operating in this sub-band has the potential to cause blocking to the receiver front-end of FDD terminals. This affects both FDD terminals 'native' to the alternative band plan region and incoming roaming FDD terminals.
Efficiency, scale and innovation	Ecosystem / scale economy/ innovation considerations	A single ubiquitous standard across multiple markets can promote the development of scale-efficient sub-markets to address different aspects of the mobile value chain, and can support innovation by encouraging investor confidence and maximising the potential market size.. The introduction of multiple technologies could have an impact on scale and innovation, and thus the benefits accruing to users.
	Less efficient use of spectrum (increased guard band spectrum)	Allocating a greater proportion of spectrum to TDD than that stipulated in the ECC Frequency Plan may increase the amount of spectrum dedicated to guard bands as a result of the creation of an additional FDD/ TDD boundary.
Regulatory protocols and implementation	The policy issue of diverging from the ECC Frequency Plan (ECC/DEC/(05)05)	The regulatory process has developed an approach to the 2.6 GHz spectrum across Europe which seeks to minimise international issues and has set market expectations. Changing this approach could damage international relationships and increase regulatory risk as perceived by industry participants.
	Increased regulatory complexity / burden	Flexibility and its implications could increase the resources and range of skills required by regulators to manage more complex spectrum auction and reassignment processes and, potentially, disputes between operators. It could also place greater responsibility on regulators to intervene on occasions, with the associated risk that a sub-optimal decision could have a market impact over a period of time.

Source: PA research

It is worth noting that interference is in fact a common underlying theme across many of the perceived issues that we have identified.

In the following sections we go on to assess these perceived issues in terms of their potential impact and discuss the extent to which, and how, the perceived issues can be managed in order to implement *FDD/ TDD flexibility* in the 2.6 GHz band.

5.2 Overview of the potential impact and management challenge of the perceived issues identified

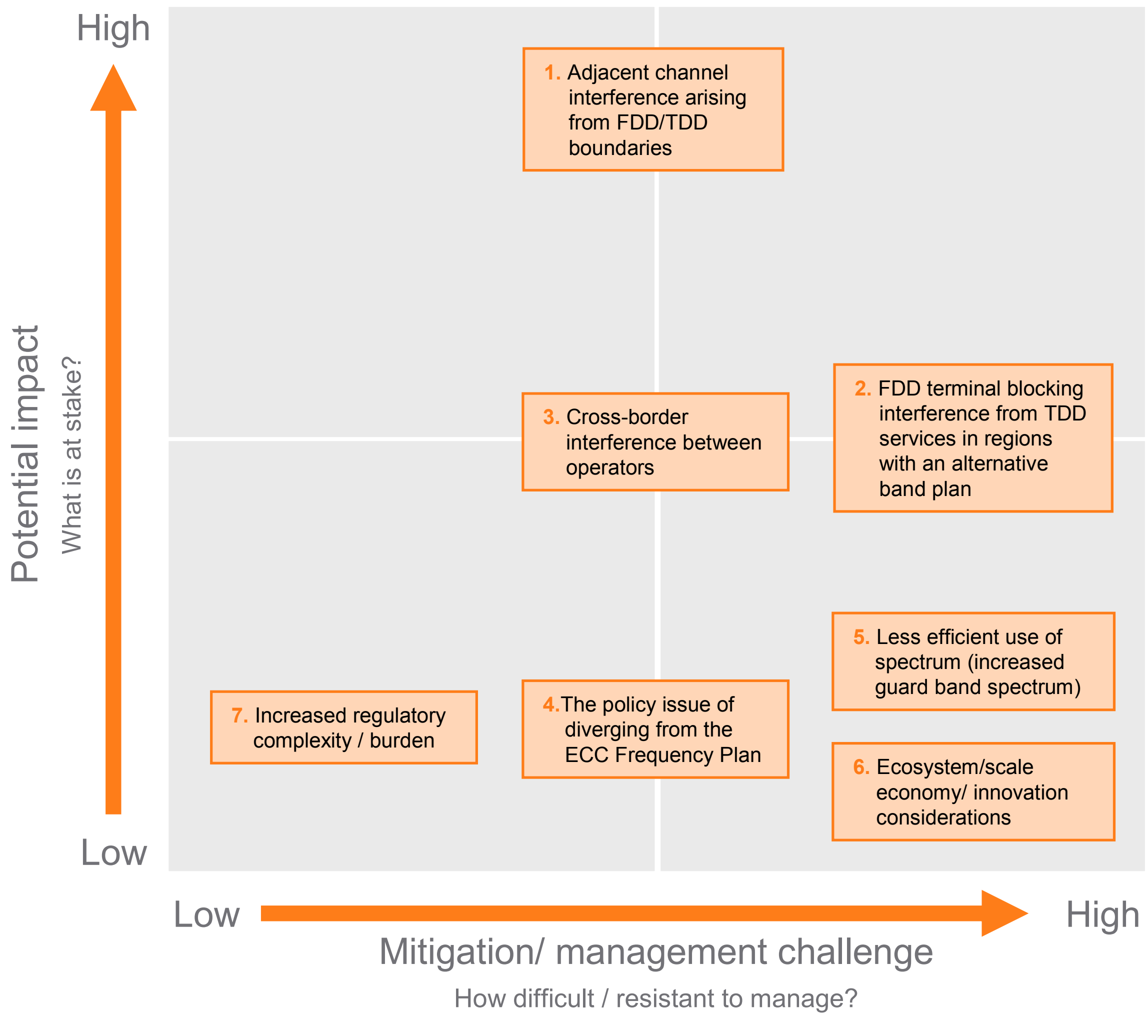
Our analysis highlights three issues that NRAs and other industry participants should focus most on when considering the implementation of FDD/ TDD flexibility:
(1) Adjacent channel interference arising from the FDD/ TDD boundary; (2) FDD terminal blocking interference from TDD services in alternative band plan regions; (3) Cross-border interference between operators; (4) The policy issue of diverging from the ECC Frequency Plan

We have reviewed each of the perceived issues highlighted above from two perspectives:

- **Potential Impact:** What is at stake in reality in terms of any likely negative impact of a perceived issue across the full community of users in a given jurisdiction (considering home-based and roaming users) as assessed after our analysis and prior to, or in the absence of, any management action to address the perceived issue?
- **Management / mitigation challenge:** To what extent can the perceived issue be managed/ mitigated; how much effort is required to manage/ mitigate it; and are any significant consequential issues created as a result?

The output of our analysis is illustrated in Figure 5-1 below.

Figure 5-1: PA's analysis of the actual importance of perceived issues with the implementation of *FDD/ TDD flexibility* in the 2.6 GHz band



Sources: PA analysis, UMTS Forum, WiMAX Forum®, Booz Allen Hamilton, OFTA, PTS, NPT, Ofcom, ECC/ CEPT

To develop the mapping shown in the figure we have adopted the following approach:

- **Independent views of impact and management:** – we have considered the potential impact and management challenge of each perceived issue separately
- **Three state scale:** – we have rated potential impact and management challenge into three broad levels: (i) 'no/ minimal' impact/ challenge; (ii) 'moderate/ significant' impact/ challenge; and (iii) 'very significant' impact/ challenge (noting that a 'very significant' impact for a small number of users may result in a 'moderate/ significant' impact in overall terms).

Our analysis indicates that only three of the perceived issues with FDD/ TDD flexibility are of significant potential impact and management/ mitigation challenge

Our analysis indicates that NRAs and other industry participants should focus most on the following three perceived issues:

- **(1) Adjacent channel interference arising from FDD/ TDD boundaries**

- **(2) FDD terminal blocking interference from TDD services in regions with alternative band plans (to ECC Frequency Plan (ECC/DEC/(05)05))**
- **(3) Cross-border interference between operators**

The underlying rationale for the importance of all of these issues is that they have the potential to affect the availability and quality of service to users – albeit that the adoption of market-based mechanisms for spectrum allocation should place these user experience concerns foremost in the minds of bidders for spectrum.

Our analysis indicates that the remaining four perceived issues identified are of less significance, though they should still be given consideration and local circumstances may increase their significance

We consider the remaining issues identified to be generally of less significance, in accordance with the rating scale above, though they still warrant attention and local circumstances may increase their significance for particular jurisdictions:

- (4) The policy issue of diverging from the ECC Frequency Plan (assuming the Commission Draft Decision (RSCOM08-02) goes on to be approved)
- (5) Less efficient use of spectrum (increased guard band spectrum)
- (6) Ecosystem/ scale economy/ innovation considerations
- (7) Increased regulatory complexity / burden

The following section sets out our detailed analysis relating to each of the seven perceived issues introduced above, with further supporting material in the appendices. The remainder of this section addresses some general assumptions and common issues relating to interference mechanisms that underlie our analysis.

5.3 General assumptions underlying our analysis

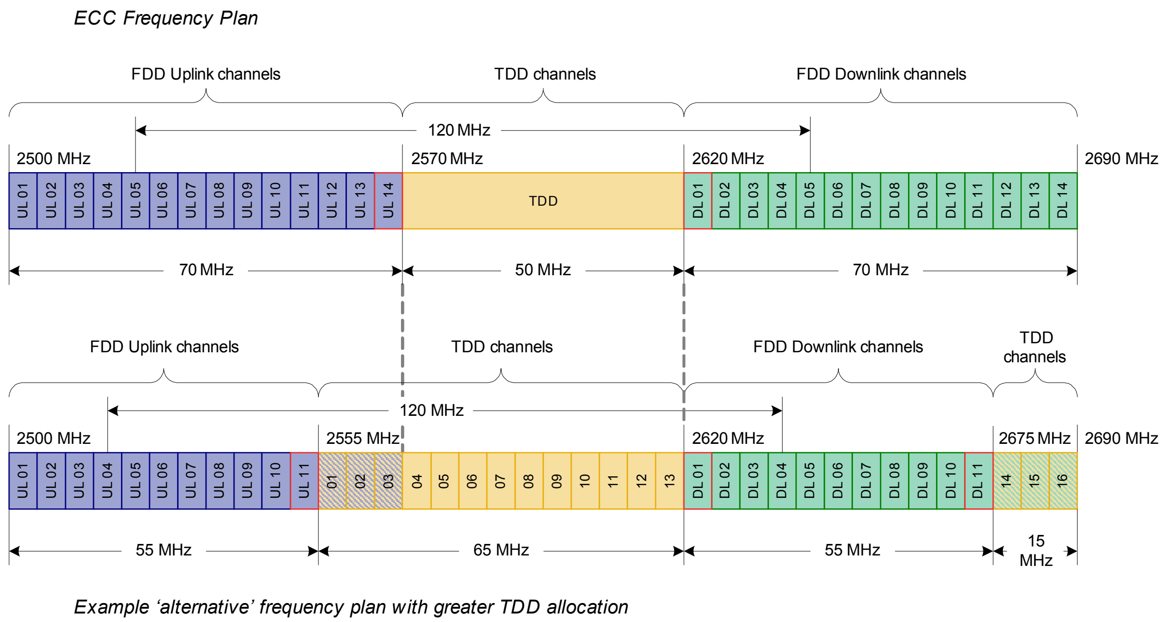
Our analysis of the perceived issues is based on some general assumptions: asymmetric Internet-like data services will be the predominant usage and OFDMA the predominantly deployed technology, with TDD deployments being time-synchronised to limit interference; vendors will not generally produce custom devices to suit band plan variations; the central sub-band will be used for TDD rather than FDD-downlink; and alternative plans will accommodate any additional TDD channels in the upper-most portions of the ECC/DEC/(05)05 defined FDD sub-bands

Our analysis of the perceived issues is based on the following general assumptions:

- The 2.6 GHz band is likely to be used predominantly for Internet-like data services, characterised by asymmetric traffic patterns biased toward higher downlink traffic levels. Wideband channels will be required to accommodate such services; more discussion on channelisation can be found in Appendix E

- The predominant technologies deployed in the 2.6 GHz band in Europe are expected to be OFDMA-based, such as WiMAX and LTE, as opposed to CDMA-based
- TDD deployments by different operators within the 2.6 GHz band will have time-synchronised uplink and downlink periods – this will prevent the most significant sources of intra-TDD interference (BS-BS and TS-TS)
- Equipment manufacturers will generally not produce custom terminal equipment to account for regional variations in the adopted 2.6 GHz band plan, either for FDD or TDD systems. This implies that FDD terminal receivers will be open to frequencies between 2620 and 2690 MHz and TDD receivers will be open to the whole 2500 to 2690 MHz band
- Regulatory authorities adhering to ECC/DEC/(05)05 will adopt the 'TDD channel' usage option in the ECC Frequency Plan (ECC/DEC/(05)05) rather than the 'FDD downlink channel paired with FDD uplink outside of the 2.6 GHz band' usage option . For more discussion on this see Appendix D
- Regulators that adopt an alternative band plan to the ECC Frequency Plan defined by ECC/DEC/(05)05 are likely to follow a structure similar to the example given in Figure 5-2 below, whereby the 120 MHz channel spacing between FDD uplink and downlink is maintained (the number of extra TDD channels shown is only an example for illustration). To achieve this, any additional TDD spectrum is taken from the upper part of the FDD uplink sub-band with an equivalent amount taken from the upper part of the FDD downlink sub-band in order to maintain FDD pairing symmetry (the upper-most parts of the FDD sub-bands may be preferred for any additional TDD spectrum in order to minimise out-of-band interference considerations). The addition of a block of TDD channels at the top end of the band introduces the need for an extra guard band between the TDD block and the remaining FDD downlink channels.

Figure 5-2: Example alternative plan for the 2.6 GHz band



Source: PA analysis, ECC/DEC/(05)05

5.4 Overview of interference mechanisms and their severity

Several of the perceived issues identified can be attributed to interference between FDD and TDD systems – this section identifies mechanisms that can interact to cause these issues and assesses their consequences

When analysing FDD/ TDD interference effects for the 2.6 GHz band it is helpful to think in terms of three root cause 'dimensions':

- **Equipment interactions** (e.g. terminal-to-terminal interference)
- **Interference classes** (e.g. adjacent channel interference)
- **Operational scenarios** (e.g. cross-border interference).

Taking these in turn, the set of equipment interactions from which interference can arise is as follows:

- **Base-station to base-station** (BS-BS) equipment interactions
- **Base-station to terminal-station** (BS-TS) equipment interactions
- **Terminal-station to base-station** (TS-BS) equipment interactions
- **Terminal-station to terminal station** (TS-TS) equipment interactions.

Each of these equipment interactions can be manifested in one of three interference classes:

- **Adjacent channel:** This interference class is due to transmitting and receiving stations operating on different but neighbouring frequency channels. The transmitting station emits power in the channels adjacent to the intended channel. The receiving station does not completely reject received signal power in channels adjacent to the intended channel. Together these two effects cause adjacent channel interference. More detail can be found in Appendix B on how different equipment interactions result in different adjacent channel interference severity. The same mechanism can also affect the 'adjacent-plus-one' channel in either direction if the interference is of sufficient magnitude
- **Co-sub-band RF front end blocking:** This class is due to the fact that terminal receiver designs can have an RF front-end that is as wide as the sub-band over which they operate. Selectivity down to a single channel bandwidth is then performed at Intermediate Frequency (IF). This means that receivers are vulnerable to blocking over the entire sub-band range of frequencies
- **Co-channel:** In this case, the two stations are operating on exactly the same frequency channel. This means they directly interfere with each other.

Finally, we can consider three separate operational scenarios under which interference may occur between an FDD and TDD station (thinking in each scenario about both FDD to TDD interference and, in the reverse case, TDD to FDD interference):

- **FDD/ TDD boundary:** The stations are operating immediately either side of the TDD/ FDD boundary within a frequency plan
- **Co-sub-band:** The stations are operating in the same sub-band; either the ECC Frequency Plan (ECC/DEC/(05)05) FDD uplink or downlink sub-band

- **Cross-border:** The stations are operating either side of a regional border.

To obtain a comprehensive view of all the potential interference effects that could be affected by the adoption of *FDD/ TDD flexibility*, we therefore need to consider 12 interference mechanisms – three interference classes each of which can occur under four different types of equipment interactions – and consider the implications of these interference mechanisms under the three operational scenarios described above (for FDD to TDD and vice versa).

Table 5-2 below summarises our assessment of the severity of interference for each resulting situation (where applicable). It is important to note that this table addresses the likely 'instantaneous' severity of the interference effect on a particular user before any attempt is made to analyse the potential impact either in terms of the frequency of occurrence and duration of the effect for the user, or in terms of the total number of users likely to be affected. The table also reflects the potential severity of interference effects prior to any action to manage the situation and the general assumptions set out in the prior section apply.

Table 5-2: 'Instantaneous' potential interference severity analysis matrix (with no statistical analysis of occurrence/ users numbers affected or mitigation efforts)

		Interference mechanism											
		Adjacent channel				Co-sub-band RF receiver front-end blocking				Co-channel			
Operational scenario		BS – BS	BS – TS	TS – BS	TS – TS	BS – BS	BS – TS	TS – BS	TS – TS	BS – BS	BS – TS	TS – BS	TS – TS
TDD -> FDD interference	**FDD/ TDD boundary**												
	FDD UL / TDD boundary	Significant	Zero	No additional	Zero								
	FDD DL / TDD boundary	Zero	No additional	Zero	Significant								
	Co-sub-band												
	TDD in FDD DL sub-band					Zero	No additional	Zero	Very significant				
	Cross-border												
	TDD in FDD UL sub-band	Significant	Zero	No additional	Zero	Zero	Zero	Zero	Zero	Very significant	Zero	Significant	Zero
	TDD in FDD DL sub-band	Zero	No additional	Zero	Significant	Zero	No additional	Zero	Very significant	Zero	Significant	Zero	Very significant
FDD -> TDD interference	**FDD/ TDD boundary**												
	FDD UL / TDD boundary	Zero	Zero	No additional	Significant								
	FDD DL / TDD boundary	Significant	No additional	Zero	Zero								
	Co-sub-band												
	TDD in FDD UL sub-band					Zero	No additional	Zero	Very significant				
	Cross-border												
	TDD in FDD UL sub-band	Zero	Zero	No additional	Significant	Zero	No additional	Zero	Very significant	Zero	Zero	Significant	Very significant
	TDD in FDD DL sub-band	Significant	No additional	Zero	Zero	Zero	Zero	Zero	Zero	Very significant	Significant	Zero	Zero

Source: PA analysis

Key:

Zero: Scenario does not cause any significant manifestation of the interference mechanism

No additional: Potential interference by this mechanism is no more significant than would be experienced in a band plan using a homogenous duplexing type (FDD or TDD as appropriate).

Minor: Interference by this mechanism has the potential to be more significant than that experienced in a band plan using a homogenous duplexing type but is unlikely to cause QoS degradation / service interruption at a level noticeable to typical users.

Significant: Interference by this mechanism has the potential to cause significant QoS degradation / service interruption if left unmanaged.

Very significant: Interference by this mechanism has the potential to cause very significant/ severe QoS degradation / service interruption if left unmanaged.

When management techniques to address the interference effects described above are considered, it is important to note that it is the mechanism by which interference is manifested that is open to management: the interference management techniques are agnostic of the underlying scenario that causes the interference.

Therefore, a matrix can be constructed to illustrate how various interference management techniques can be applied to the 12 interference mechanisms without reference to any specific interference scenario. This is shown in Table 5-3.

Table 5-3: Strategies to manage specific FDD/ TDD interference mechanisms

Interference management strategy	Interference mechanism											
	Adjacent channel				Co-sub-band				Co-channel			
	BS – BS	BS – TS	TS – BS	TS – TS	BS – BS	BS – TS	TS – BS	TS – TS	BS – BS	BS – TS	TS – BS	TS – TS
Regulator driven												
Mandate appropriate guard bands	✓	✓	✓	✓								
Apply appropriate emission specifications	✓	✓	✓	✓					✓	✓	✓	✓
Inter-operator co-ordination												
Base station co-location (geographic)		✓				✓						
Base station separation (mast position/directivity)	✓								✓			
Cell frequency channel allocation	✓	✓	✓	✓					✓	✓	✓	✓
Equipment design												
Multiple terminal receiver front-end filtering paths						✓		✓				
Active antenna systems (beam-forming)	✓	✓				✓			✓	✓		
Transmitter / receiver performance (ACLR / ACS)	✓	✓							✓	✓		

Source: PA analysis

6 Analysis of perceived issues relating to the implementation of FDD/TDD flexibility

In this section, we address in more detail the perceived issues with implementing flexibility in the 2.6 GHz band, addressing first the issues we consider to be of greater significance, as highlighted in the prior section, and building on the discussion of general assumptions and common interference themes also discussed in the prior section. This section also includes a summary of potential management approaches for the perceived issues identified.

6.1 Adjacent channel interference arising from FDD/ TDD boundaries

Adjacent channel interference occurs at TDD/FDD boundaries and must be managed – guard bands are the primary management method, although further techniques can be used to minimise the size of required guard bands

6.1.1 Potential Impact

Without management, there is the potential for very significant adjacent channel interference between FDD and TDD systems at the boundary between FDD and TDD allocated spectrum

This effect occurs in both the ECC Frequency Plan (ECC/DEC/(05)05) and any alternative frequency plan that includes both FDD and TDD technologies.

This interference potential arises due to four mechanisms:

- TDD terminals transmitting adjacent (in frequency terms) to the FDD downlink sub-band and interfering with FDD terminal receivers
- TDD base stations transmitting adjacent to the FDD uplink sub-band and interfering with FDD BS receivers
- FDD terminals transmitting adjacent to a TDD sub-band and interfering with TDD terminal receivers
- FDD base stations transmitting adjacent to a TDD sub-band and interfering with TDD base stations.

These mechanisms and their severity are summarised in Section 5.4 above. There is also a more detailed discussion of adjacent channel interference and its relative severity under different scenarios in Appendix B.

The opportunity for very significant interference will be present wherever there are adjacent TDD and FDD sub-bands. Under the ECC Frequency Plan (ECC/DEC/(05)05) there are two boundaries where this can occur. As discussed above (Section 5.3) it is likely that alternative band plans with a greater proportion of TDD allocation would have more such boundaries.

The impact when such interference does occur will be experienced by users as reduced Quality of Service (QoS) or increased drop-out rates/ loss of service.

An assessment of the severity of such adjacent channel interference if no management action is taken can be found both in the draft ECC Report 119[30] and the report by Mason Communications Ltd commissioned by Ofcom[31]. Figures for the additional isolation required, not taking into account the probability of occurrence of the interference mechanisms, are shown in Table 6-1.

Table 6-1: Figures for excess isolation required to prevent interference

Source	Excess isolation required / dB			
	TDD → FDD		FDD → TDD	
	BS – BS 100 m separation	TS – TS 10 m separation	BS – BS 100 m separation	TS – TS 10 m separation
Draft ECC Report 119	45.3 / 37.3 *	45.3 (3.5 m separation)	57.3 / 49.3 *	48.3 (3.5 m separation)
Mason Report (No Mitigation)	41.9	24.9	57.3	29.4
Mason Report (Mitigation)	-23.1	24.9	-7.7	29.4

* These figures have been adjusted to account for 5 MHz guard bands

Source: PA analysis, ECC, Mason/ Ofcom

Both reports demonstrate that a considerable amount of extra isolation is required. The Mason report indicates that this is possible in the case of BS interference sources.

It should be noted that in the specific case of TS-TS interference, the probability of occurrence of interference arising due to this mechanism is very low. Detailed analysis in the more recent Ofcom report indicates that TS-TS interference in the 2nd adjacent channel is insignificant.[32] This implies that a 5 MHz guard band is sufficient to prevent TS-TS adjacent interference between FDD and TDD terminals or vice versa. Further discussion of this point can be found in Section 6.2.2 below.

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[30] Draft ECC Report on coexistence between mobile systems in the 2.6GHz frequency band at the FDD/ TDDFDD/ TDD (or TDD/TDD unsynchronised) boundary, Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations

[31] 2500-2690MHz, 2010-2025MHz and 2290-2302MHz Spectrum Awards Engineering Study, 22 November 2006, Mason Communications Ltd. commissioned by Ofcom

[32] On the impact of interference from TDD terminal stations to FDD terminal stations in the 2.6 GHz band, Ofcom, 21 April 2008

6.1.2 Issue Management

Guard bands are required to manage adjacent channel interference – their size can be minimised by employing a number of further techniques

Guard bands (nominally unused spectrum) between the FDD and TDD allocations exploit the selectivity of the receiver to reduce interference. Wider guard bands provide greater levels of protection, whilst resulting in a less efficient allocation of spectrum, hence a regulator will be seeking to minimise the size and number of guard bands.

The width of the guard bands can be determined by the regulator. In support of this the regulator will wish to define an appropriate emission specification process (e.g. Block Edge Masks) and perhaps a fall-back legal process under which the interferer is obliged to manage any specific interference locations. In doing this, the interfering operator can take into account a number of site engineering processes which can be used to manage interference on a site-by-site basis (see following sub-sections). Such a process can avoid the over-specification of guard band widths.

Guard band widths

Guard bands separate TDD blocks from FDD blocks, creating a buffer zone that ensures that spectrum in active use does not suffer from interference. Regulators can specify guard bands of an appropriate size.

The Mason report commissioned by Ofcom[31] suggests that a minimum of a 10 MHz separation is required between TDD and FDD carriers (based on a 5 MHz channel width) to allow acceptable levels of interference, implying a 5 MHz guard band requirement.

PA has carried out some modelling work and practical measurements into the interaction of CDMA TDD and FDD systems which suggest that 5 MHz spacing between modulated signal edges is required to eliminate interference between TDD and FDD systems. Under the conditions evaluated in these models link loss will not occur until the spacing is reduced to 1.5 MHz, with a reduction in capacity between 1.5 and 5 MHz.

CEPT Report 019 also suggests that 5 MHz guard bands are appropriate.

Therefore there is consensus from three independent sources (Mason, PA, and CEPT) that 5 MHz guard bands are sufficient.

The ECC Frequency Plan (ECC/DEC/(05)05) mandates that any guard band spectrum is absorbed by the central 50 MHz sub-band. In essence, therefore, the amount of spectrum available for TDD services in the central sub-band is reduced by an amount equivalent to any required guard bands. Assuming that two 5 MHz guard bands are employed, only 40 MHz of TDD spectrum would be available for TDD services. This introduces a significant restriction on the number of TDD operators that can co-exist in the band and provide compelling wideband services – in fact, assuming that

30 MHz bandwidth is required for TDD based providers of such services[33], only a single TDD operator may be competitively viable in the 2.6 GHz band under the ECC Frequency Plan (ECC/DEC/(05)05).

One regulatory approach is to specify and remove the guard bands from the auction. Regulators acting to reserve spectrum for guard bands avoid the undesirable occurrence of TDD lots within a spectrum auction having uncertain value due to their proximity to an FDD/ TDD boundary. By reserving, and therefore not auctioning the slots this uncertainty is removed. However, this runs counter to the policy of a full auction.

An alternative approach to a completely empty guard band is to allow power levels equivalent to picocell deployments in the FDD/ TDD boundary channels – this will reduce the effectiveness of the guard band. This preserves the spectrum value certainty introduced by the presence of a guard band whilst maximising spectral efficiency. Such a 'constrained-use' channel may command a lower price at auction.

Table 6-2 shows that a variety of countries have already chosen to deploy 5 MHz guard bands in the 2.6 GHz band.

Table 6-2: Guard bands and emissions specifications for the 2.6 GHz band

Country	Guard bands	Emissions
Hong Kong	5 MHz	Block-edge EIRP mask (mutually agreed divergence permitted)
Japan	5 MHz	NA
Norway	5 MHz band with reduced power – operators must negotiate if this power is too high	Block-edge EIRP mask
New Zealand	5 MHz – can be relaxed under mutual agreement	Block-edge EIRP mask (mutually agreed divergence permitted)
Singapore	No explicit guard bands defined: mutual agreement between operators relied upon	Field strength – based advisory conditions
Sweden	5 MHz (pico-cellular power levels permitted)	Block-edge EIRP mask
United Kingdom	5 MHz at top end of central sub-band will not be auctioned and 5 MHz restricted band at lower end of central sub-band allowing only low (picocellular) power transmissions	Block-edge EIRP mask

Source: National regulatory authorities

[33] A review of Spectrum Requirements for Mobile WiMAX Equipment to Support Wireless Personal Broadband Services, September 2007, WiMAX Forum

Emission Specifications

The second activity that regulators need to perform to prevent FDD/ TDD boundary interference, whilst maximising spectral utility, is to specify appropriately permitted emission limits. Techniques for achieving this whilst maintaining technology neutrality are described in Appendix C. The most appropriate and most widely adopted of these is the Block Edge Mask (BEM) approach

Table 6-2 also illustrates the choice of emission spectrum management technique made by a variety of regulatory authorities.

Legal remedies

Inevitably there will still be some potential for interference between services and this may be one-sided with the FDD party being aggrieved. Regulators may wish to provide a formal process for intermediation in order to require operators to act on specific interference occurrences. In doing this the regulator may take note of a range of practical site engineering and cooperation activities in which the operators may engage. These are detailed below and apply mainly to the BS-BS interference causes.

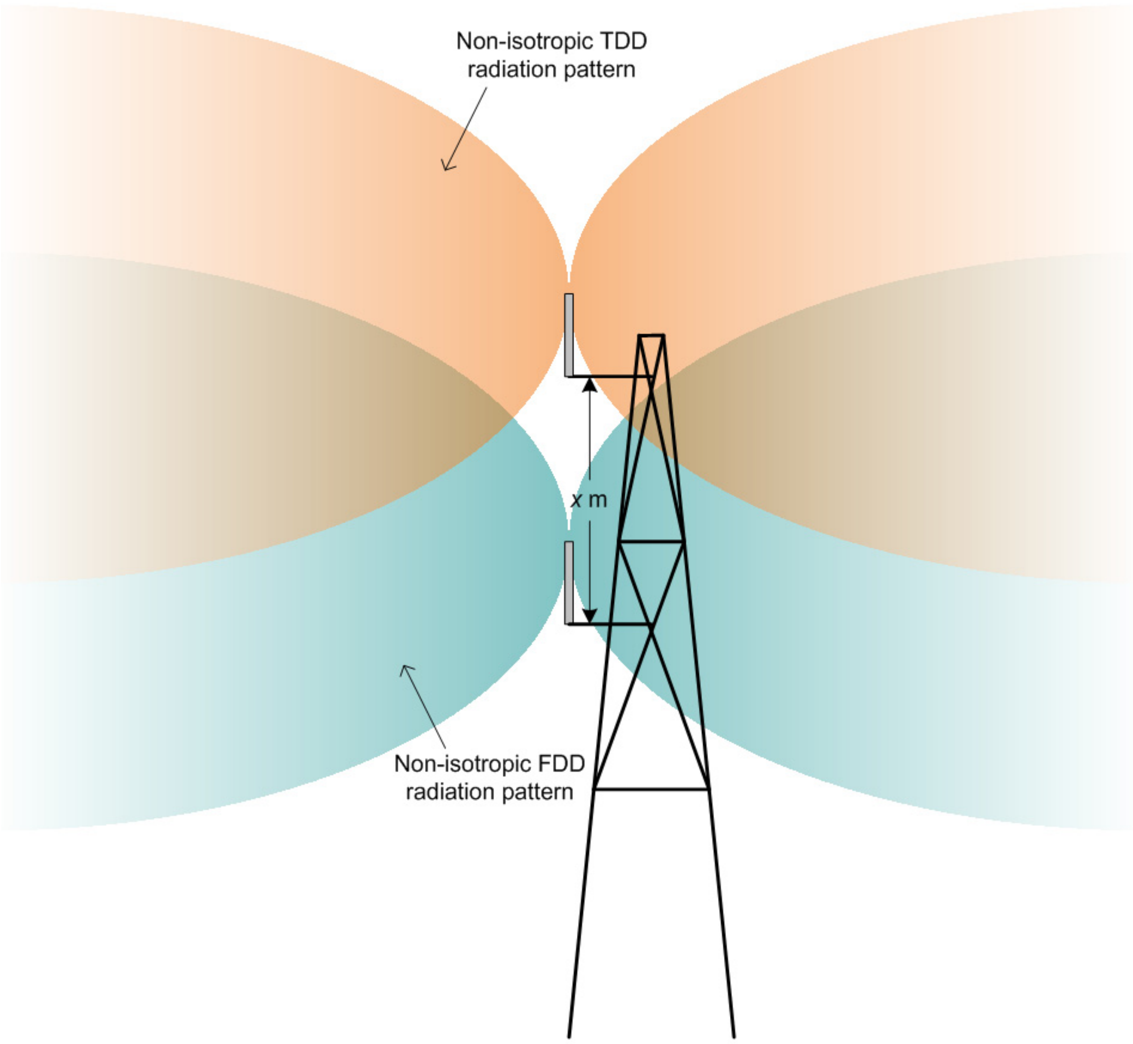
Inter-operator coordination

Operators can work together to minimise interference by:

- Locating FDD and TDD base stations in the same geographic location
- Separating base stations vertically or through antenna directivity
- Appropriate cell channel allocation.

BS-BS interference between TDD systems adjacent in frequency to the FDD UL can be minimised by careful location of base stations. This can be achieved geographically, or in terms of vertical separation, or by means of management of antenna radiation patterns. The two latter options are preferred as geographical separation can in fact worsen TDD BS – FDD TS interference. See Figure 6-1 below.

Figure 6-1: BS antenna separation by vertical spacing and antenna radiation patterns



Source: PA analysis

TDD BS – FDD TS interference on adjacent channels is at its most significant when the FDD terminal is geographically closer to an operational TDD BS than the FDD BS of its own cell. This results in the interferer (TDD) signal being higher in strength than the wanted (FDD) signal. When this signal strength difference is similar to, or greater than, the relevant ACIR (see Appendix B), significant interference will be experienced. By co-locating the TDD and FDD BS, the wanted and interferer signals will be of similar strength (assuming common transmit power), so the ACIR operating between the TDD BS and FDD terminal ensures no significant interference will result.

Cell channel allocation across a given geography is a very effective adjacent channel interference management technique. If both TDD and FDD operators have a sufficiently numerous choice of channels, then cell channel frequencies can be chosen such that geographically overlapping FDD/ TDD cells do not use adjacent frequencies. However, the likelihood of there being sufficient available channels to achieve this effectively is reduced as the choice of channel bandwidth increases (e.g. to 10 or even 20 MHz).

Technical approaches to minimise interference

In addition, there are a number of technical approaches that could be employed to ensure interference is minimised. These are:

- Equipping BS receivers with more stringent receiver front-end filtering
- Implementing Active Antenna Systems (AAS) in BS equipment
- General improvements in transmitter/ receiver performance (ACLR/ACS).

The constraints on size, power and unit cost are less stringent in BS than TS equipment, so there is scope for increased receiver front-end filtering at smaller cost in proportion to overall network deployment.

Electronic beam steering and active cancellation techniques (Adaptive Antenna Systems) can be used to direct the signal in a specific orientation. These techniques also lend themselves more to BS than TS implementation. This is primarily because they require multiple, spatially diverse, antennae which do not readily fit into a TS form factor, but also due to cost and processing power requirements. These techniques do have to be used with caution; non-linear modulation products that appear in an adjacent channel will not necessarily be steered in the same direction as the wanted emissions, resulting in the potential to increase interference.

Residual Issues for Regulators

Each of these interference management techniques has a cost associated with it, and regulators need to understand the trade-off between the benefit of management and the costs of implementing the solution.

Encouraging operators to coordinate to reduce interference has been successful in the GSM world. This is the approach favoured by regulators, with the aim of allowing industry participants to reach their own resolution to a problem. This approach minimises cost. However, conflict between FDD and TDD operators could be exacerbated by the nature of the interference mechanisms, which are asymmetric – i.e. the FDD operators may suffer from additional interference whereas TDD operators may not.

The regulatory management of interference is therefore required. Regulators have responded by specifying guard band and emissions requirements, at the same time as encouraging operators to settle differences themselves. Appendix C summarises the different approaches taken by regulators.

Different countries therefore take different approaches. Both guard bands and emissions specifications can affect the efficient use of spectrum. Regulators could, however, accept the trade off that some interference can be tolerated to facilitate increased utilisation of spectrum and the inclusion of competing technologies.

6.2 FDD terminal blocking interference from TDD services in regions with an alternative band plan

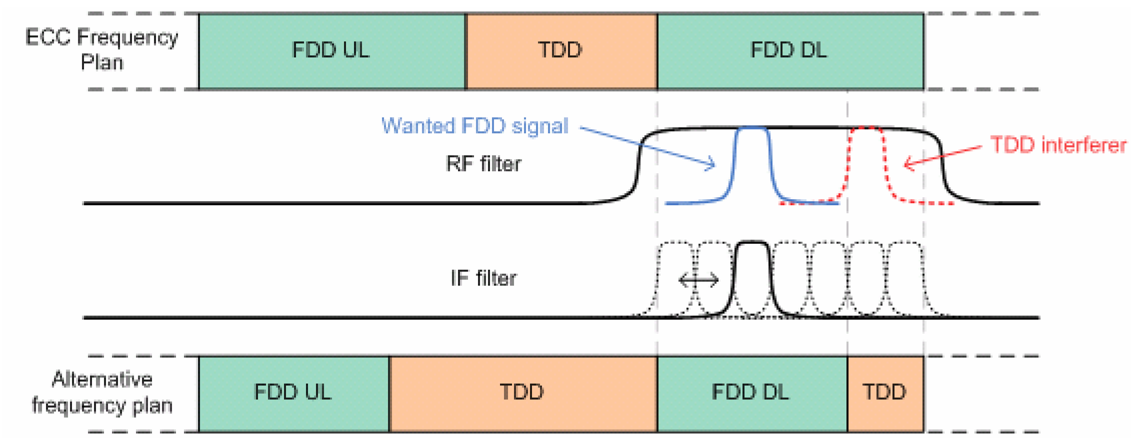
In regions with an alternative frequency plan, TDD services may be present in the ECC Frequency Plan (ECC/DEC/(05)05) FDD DL Sub-Band and TDD Terminals using these services may cause blocking of the RF Front end of FDD terminals – however, a statistical analysis suggests this is unlikely to occur

6.2.1 Potential Impact

Blocking of FDD terminals by TDD terminals has the potential to cause very significant interference in some circumstances

The RF receiver front end of an FDD terminal designed to meet the requirements of the ECC Frequency Plan (ECC/DEC/(05)05) is likely to be open to the entire 2620 – 2690 MHz sub-band, with channel filtering performed at Intermediate Frequency (IF). If such a terminal were to be used in a non-ECC Frequency Plan (ECC/DEC/(05)05) band plan, TDD terminal users on channels that fell within the receiver front-end bandwidth could cause very significant interference to FDD receiving terminals in some circumstances, as shown in Figure 6-2.

Figure 6-2: A TDD system in a channel within the ECC Frequency Plan (ECC/DEC/(05)05) FDD DL sub-band could interfere with an FDD handset by means of RF font-end blocking



Source: PA analysis

This has the potential to affect both FDD terminals 'native' to a region with an alternative band plan as well as any FDD terminals roaming into such a region.

An equivalent situation also arises when an FDD terminal transmits in the FDD uplink sub-band; this can cause blocking in a TDD terminal front-end.

6.2.2 Issue Management

A statistical analysis suggests that this inference problem has a low probability of being manifested and is also likely to be dealt with transparently to the user by means of error

correction and retransmission – physical management of the issue using custom equipment is unattractive due to technical and economic considerations

An assessment of the severity of terminal-to-terminal interference can be made by considering user traffic statistics and user-to-user proximity.

Such interference occurs when terminals are transmitting in close proximity. Terminals are used, however, only for a small proportion of the time. Even when they are being used, actual transmit activity (for data applications) occurs only for a further small fraction of time. In typical TDD multimedia applications uplink transmit traffic occurs during less than 5% of the call/ session.

We have estimated, taking account of the likely transmission duty cycle for TDD terminals together with the user proximity needed to cause interference, that under typical user distributions TDD to FDD co-sub-band terminal-to-terminal interference is likely to occur for only a very small proportion of the time.

There will, of course, be specific interference events that do occur for a given user; specifically where there are high concentrations of users, such as at airports, conferences etc. However, when modern error correction and re-transmission techniques are considered, the interference effects are generally likely to be of little or no practical impact to a typical user (considering that data in all modern systems is coded using redundant data bits to provide resilience against bursts or blocks of interference). A typical coding scheme used in 3G systems will allow for a good proportion of the data to be totally corrupted, without causing damage to the final data quality. The errors are automatically corrected within the terminal. This mechanism means that a bursty interference, such as a 10% duty cycle interferer, will have no perceptible effect on a (previously) good quality signal. It will, however, reduce the overall error margin of the system. Finally, if errors are present in the decoded data, then most applications will provide for retransmission. The user will then perceive some increase in latency and the network will suffer additional traffic. Statistically, this performance degradation will be very small until the population of users and their traffic patterns increase to very high densities.

Alternatively, a potential approach to physically managing the problem of TDD systems interfering with FDD equipment in their downlink sub-band is to produce custom equipment. FDD terminals for an alternative frequency plan would have a narrower receiver front end than for the ECC Frequency Plan (ECC/DEC/(05)05). This is not considered an attractive option, however, for two reasons:

- It is technically difficult to produce a RF front-end filter with sufficiently steep roll-off to make a large difference to rejection of TDD interferers
- Manufacturers are unlikely to be willing to produce custom equipment for each region with an alternative band plan.

6.3 Cross-border interference between operators

Where two neighbouring regions adopt differing band plans the severity of cross-border interference between FDD and TDD systems is increased – management strategies are available to limit this increase

6.3.1 Potential Impact

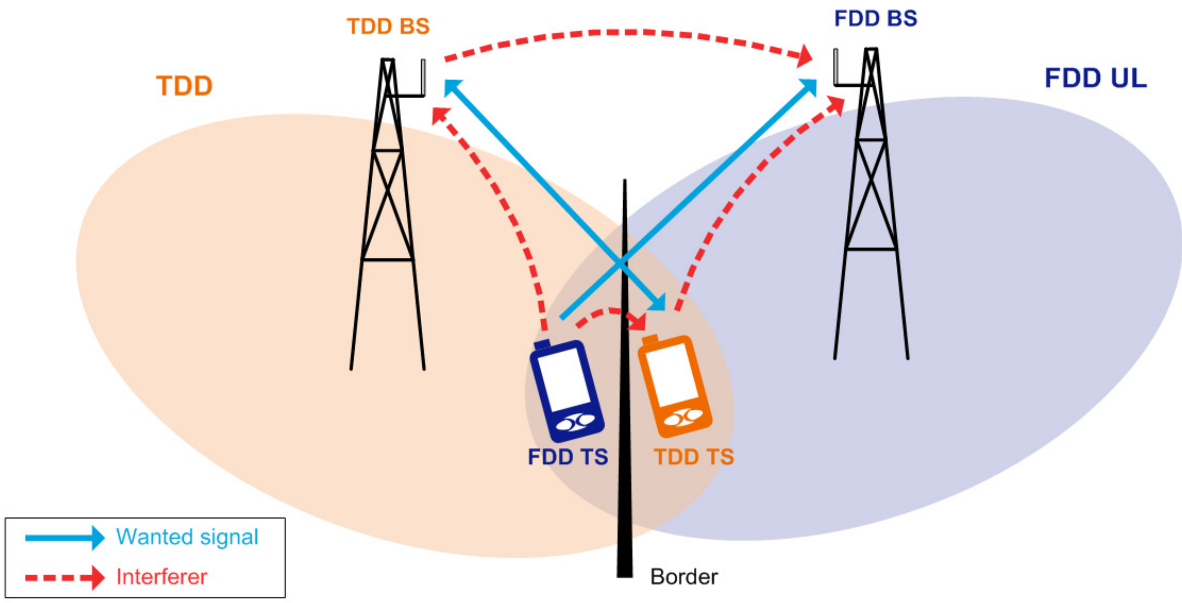
Without management, cross-border interference issues may lead to degradation or interruption of service

In addition to any interference mechanisms that may occur within a region, there are specific cross-border interference mechanisms that could arise as a result of co-channel interference. Whilst this is an issue that has to be managed in any multi-region wireless communications deployment, the adoption of differing FDD/ TDD band plans in neighbouring regions increases the potential interference severity compared to a ubiquitously-adopted band plan.

Co-channel interference could arise by any of the four possible equipment interaction routes (BS-BS, BS-TS, TS-BS or TS-TS) where border-deployed TDD systems in one region occupy either the FDD UL or DL sub-bands of a neighbouring region. Each of these four possible mechanisms can also arise in the situation where a TDD channel sits either in an FDD UL channel (Figure 6-3) or an FDD DL channel (

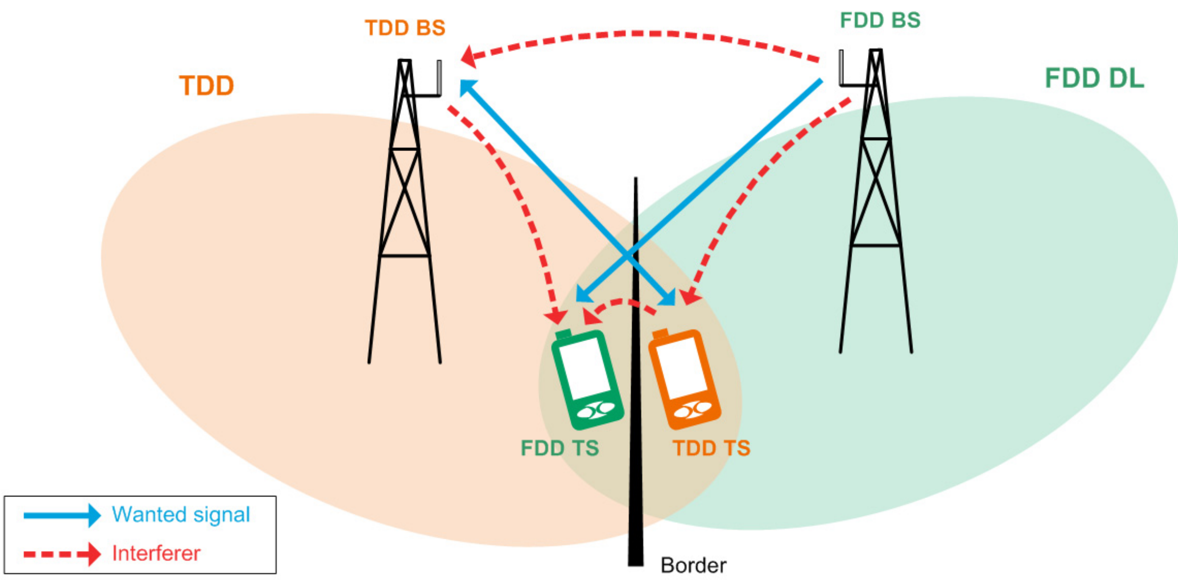
Figure 6-4).

Figure 6-3: Cross border interference TDD – FDD UL



Source: PA analysis

Figure 6-4: Cross-border interference for TDD – FDD DL



Source: PA analysis

The interference mechanism and severity matrix provided in Section 5.4 above highlights the severity of each interference type.

The matrix shows that the significant sources of cross-border interference if no interference management techniques are employed are terminal-to-terminal interference (in adjacent channels, co-sub-band and co-channel) together with base station-to-base station interference (adjacent and co-channel).

The terminal-to-terminal interference mechanisms can be discounted on the basis of probability of occurrence, as discussed in Section 6.2.2, and considering that the QoS effects from such interference are likely to be transparent to the user after error correction and re-transmission.

However, without management, the base station to base station interference is likely to have a significant impact on Quality of Service (QoS) or increased drop-out rates / loss of service, especially in the co-channel case.

It should also be considered that the area of a region neighbouring a border is likely to be a small proportion of the total region area in most cases. This immediately reduces the impact of cross-border interference to only a small proportion of users.

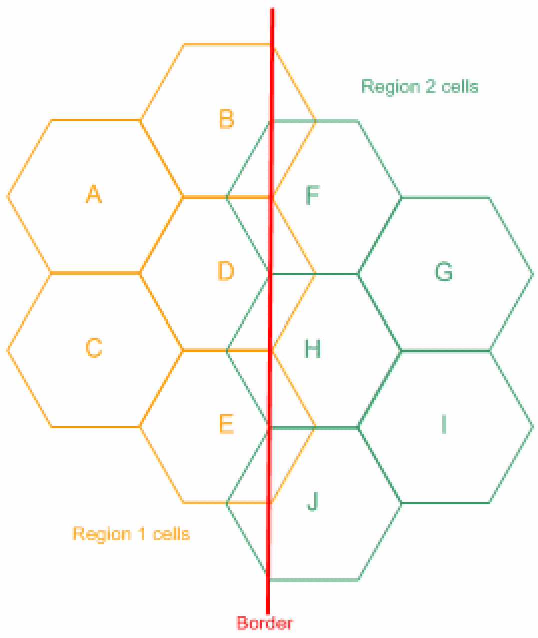
6.3.2 Issue management

Both technical solutions and co-operation strategies can be used to manage cross-border interference

Cross-border interference effects arising due to adjacent channel interference can be managed in an identical fashion to adjacent channel interference within a region – these techniques, including appropriate regulatory specifications, inter-operator co-ordination and various technology-based approaches are described in Section 6.1.2.

The same techniques can also be used to combat co-channel interference; however, their relative priority changes. Whereas intra-region adjacent channel interference effects primarily arise where FDD and TDD cells have a significant overlap, or are co-located, any reasonable border cell deployment will aim to minimise cross-border cell overlap, such as in the example cell plan in Figure 6-5. This coupled with the fact that the benefit of a high ACIR (see Appendix B) disappears when considering co-channel interference, means that technology-based solutions and regulatory specifications become much less important. Inter-region operator co-operation is, therefore, the prime cross-border interference combating mechanism.

Figure 6-5: Example hypothetical cross-border cell plan

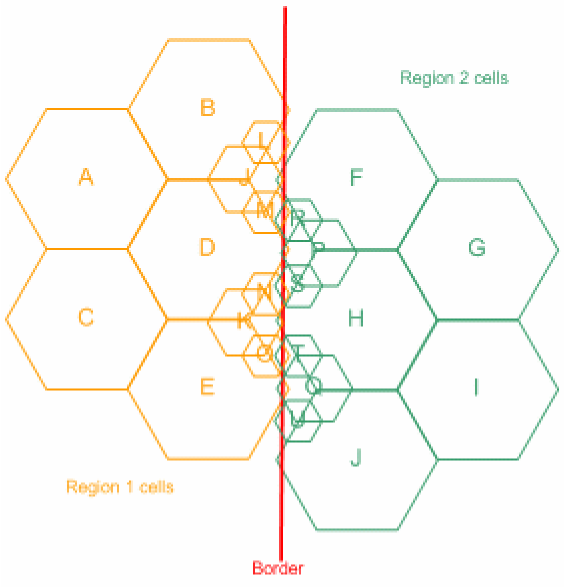


Source: PA analysis

The prime focus of cross-border operator co-operation should be to ensure that the choice of channel for a TDD service on one side of, and adjacent to, a border is not re-used for an FDD service in a neighbouring cell the other side of the border. In Figure 6-5 examples of such cross-border neighbouring cell pairs where frequency re-use is unadvisable are B-F, D-F, D-H, E-H and E-J.

Another strategy that can be used by operators is to use lower power base stations to fill in coverage gaps adjacent to borders. Such a strategy is illustrated in Figure 6-6. A related technique is to use directional antennae on macro base stations such that the antenna main lobes point away from borders. Both of these solutions will incur additional costs. These costs will be slight in the case of adding directional antennas. The viability of using lower power base stations to facilitate a greater macro base station separation will depend on the particular geography and the number of users likely to require services within a border region. A large number of users will increase the viability of employing additional base stations.

Figure 6-6: Hypothetical cross-border cell plan using lower-power base stations for coverage 'fill-in'



Source: PA analysis

Table 6-3 shows how all of these approaches can be used to manage the interference mechanisms.

Table 6-3: Summary of where cross-border interference management is relevant

	Interference mechanism						
	Adjacent channel		Co-sub-band	Co-channel			
Interference management strategy	BS – BS	TS – TS	TS – TS	BS – BS	BS – TS	TS – BS	TS – TS
Regulator driven							
Mandate appropriate guard bands	✓	✓					
Apply appropriate emission specifications	✓	✓		✓	✓	✓	✓
Inter-operator co-ordination							
Base station co-location (geographic)							
Base station separation (mast position / directivity)	✓			✓			
Cell frequency channel allocation	✓	✓		✓	✓	✓	✓
Equipment design							

	Interference mechanism						
Multiple terminal receiver front-end filtering paths			✓				
Active antenna systems (beam-forming)	✓			✓	✓		
Transmitter / receiver performance (ACLR / ACS)	✓			✓	✓		

Source: PA analysis

Although cross-border interference is an issue that regulators have experience of addressing through mutual agreement, the implementation of flexibility could exacerbate the issue. Cross-border coordination is required whatever spectrum allocation is used but the increased opportunity for interference resulting from a lack of uniformity in band plans may lead to an increase in the instance and severity of problems. Regulators in countries with a number of borders could face the problem of managing cross-border interference between several operators. This could require the regulator to play a greater role in managing cross-border relationships, an issue which is examined further in Section 6.7.

Evidence that such multi-region co-operation is a viable proposition is available from CEPT. The CEPT draft recommendation for the 900 and 1800 MHz bands[34] suggests methods for co-operation between operators/ regulators across borders and recommend that these are put in place. Whilst the mechanisms suggested for cross-border co-ordination are between specific, related technologies, the underlying principles of the recommendation, such as the political feasibility of such co-operation, are equally applicable to the diverse technologies likely to inhabit the 2.6 GHz band.

6.4 The policy issue of diverging from the ECC Frequency Plan

Regulators agreed the framework for the 2.6 GHz band after due consideration, and regulatory stability is important for all stakeholders – however, there is provision for adapting decisions and frameworks to changing circumstances when necessary

6.4.1 Potential impact

Potential Impact: ***Divergence from the plan could harm international regulatory co-operation and increase industry participants' perspectives of regulatory risk***

Regulatory decisions are often made with a view to underpinning market and industry development over a timeframe of five, ten or more years. This is a highly challenging task given fast-moving changes in technology, user behaviour, economic conditions and political factors.

[34] Draft ECC Recommendation (07)XX: Frequency Planning And Frequency Coordination For The GSM 900 (including E-GSM1) / UMTS 900, GSM 1800/UMTS 1800 Land Mobile Systems (Except direct mode operation (DMO) channels), Electronic Communications Committee (ECC) within the Conference of Postal and Telecommunications Administrations (CEPT)

It took over five years for consensus over the use and allocation of spectrum in the 2.6 GHz band to emerge, as crystallised in the ECC Frequency Plan (ECC/DEC/(05)05). Since that time, policy has developed at both European and national levels and technology, innovation and user behaviour have moved on considerably. Whilst regulators are ready to adapt policy to changing circumstances they are also cognisant of the need to avoid creating uncertainty and increased perceptions of 'regulatory risk' by making policy changes too frequently. The challenge for regulators, therefore, is to regulate in broad enough terms, in relation to the policy review cycle, in order to avoid un-necessary constraints on market and industry development.

6.4.2 Issue management

Issue management: *There are precedents for interpretation of policy over the 2.6 GHz band and a framework in place for making periodic policy reviews*

The European Commission, through the WAPECS initiative, has encouraged supra-national bodies to investigate ways of managing the interference issues raised by the flexible allocation of spectrum.

Some regulators have already indicated willingness to implement a flexible approach to the 2.6 GHz band, adopting the principles of service neutrality, technology neutrality and flexibility in the allocation of FDD/ TDD spectrum:

- The Norwegian regulator has implemented a flexible approach to FDD/ TDD allocation featuring 60 MHz of spectrum that could have been allocated to either FDD or TDD in addition to the central sub-band, with the caveat of conforming to future CEPT announcements concerning the band.
- The Swedish regulator has used the ECC Frequency Plan (ECC/DEC/(05)05) as the basis for its auction but has provided for the possibility of a change of use from FDD to TDD following the auction.
- The UK regulator, based on the latest available proposals at the time of writing, is proposing a highly flexible approach featuring 5 MHz auction bocks in the central sub-band and the ability for the market to influence fully the proportion of TDD and FDD spectrum allocated, whist maintaining the 120 MHz separation between FDD uplink and downlink channels.

The recent Draft Commission Decision on the harmonisation of the 2.6 GHz band (RSCOM08-02) gives greater scope for flexible approaches such as these. The decision supports regulators' ability to reflect local circumstances regarding the degree of flexibility in the allocation of spectrum, at the same time as requiring regulators to preserve the structural integrity of the ECC band plan, with:

- 5 MHz blocks
- 120 MHz duplex spacing
- 50 MHz central sub-band between 2570-2620 MHz with usage to be compliant with specific Block Edge Mask criteria.[35]

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[35] RSCOM08-02, 04/04/08

These precedents demonstrate how regulatory frameworks can evolve in the light of market and policy developments. Indeed, under the ECC governance model there is scope for triennial review of ECC decisions such as the ECC Frequency Plan ECC/DEC/(05)05. Any such re-assessment could broaden the scope of the 2.6 GHz band beyond IMT2000/UMTS, bringing the ECC decision into line with the emerging broad consensus on technology and service neutrality, and would enable consideration of the specific issues relating to *FDD/ TDD flexibility* discussed in this paper.

When finalising their strategies for the 2.6 GHz band, including the issue of flexibility, regulators will clearly also carefully consider important local market factors such as:

- **The level of demand for 2.6 GHz spectrum** – if a market has a relatively small number of mobile operators there is less likely to be intense competition for FDD spectrum; the regulator may therefore allow flexibility of allocation between FDD and TDD spectrum in line with an aim of assigning all spectrum
- **The need to provide additional stimulus to competition** – depending on the number and performance of incumbent operators, the implementation of flexibility may be a welcome opportunity for the regulator to stimulate increased competition by providing an opportunity for new entrants, new forms of competitions and the introduction of new business models
- **The impact on neighbouring countries** – maintaining cordial international relationships is paramount to regulators and this was one of the drivers behind unifying the band plans for 2.6 GHz spectrum across Europe; the number of neighbouring bilateral agreements that need to be negotiated is likely to be a factor that regulators consider in relation to the implementation of *FDD/ TDD flexibility*.

6.5 Less efficient use of spectrum (increased guard band spectrum)

The requirement for guard bands means that if more TDD spectrum is allocated than envisaged in the ECC Frequency Plan (ECC/DEC/(05)05) the number of guard bands will increase by at least one – however, as TDD services may more efficiently utilise spectrum for the provision of wireless broadband services, the overall impact on spectral efficiency could be positive

6.5.1 Potential Impact

The extra guard bands likely to be required for an increased TDD allocation relative to the ECC Frequency Plan (ECC/DEC/(05)05) reduce the amount of allocated spectrum for service provision

Guard bands manage the interference issues identified in Section 6.1. A greater TDD allocation than that in the ECC Frequency Plan (ECC/DEC/(05)05) is likely to lead to the introduction of at least one additional guard band if 120 MHz UL/DL FDD sub-band spacing is maintained. Given that the total 2.5-2.69 GHz band contains a possible 38 5 MHz channels, and that the maximum guard band size is 5 MHz, this implies a 2.6% reduction in available spectrum, and therefore capacity, within the band for each TDD sub-band that is allocated.

6.5.2 Issue Management

Efficiency gains from assigning more TDD channels are likely to outweigh any losses from introducing guard bands

However, this simplistic analysis ignores the fact that TDD systems are inherently more bandwidth efficient than FDD systems in most real usage scenarios involving data/ wireless broadband as they allow an asymmetric division between uplink and downlink traffic. Most current high-bandwidth applications use proportionally more downlink than uplink bandwidth. Example figures in Table 6-4 illustrate the typical uplink and downlink requirements of the applications that wireless broadband services using 2.6 GHz spectrum are likely to exhibit. [36]

Table 6-4: Downlink : uplink traffic ratios for typical usage patterns

Application	Ratio downlink: uplink
Speech or video call	1:1
Medium multimedia	1:0.026
High multimedia	1:0.005

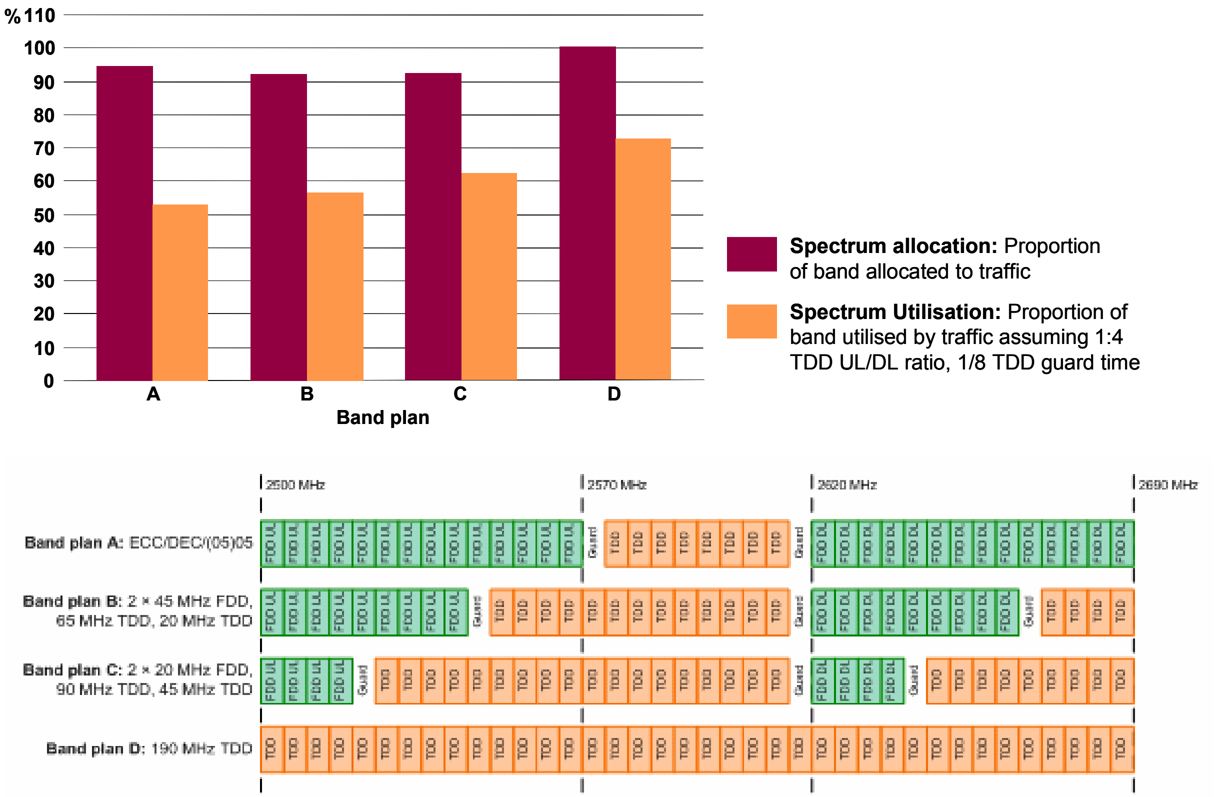
Source: Proc. of the 5th IFIP-TC6 International Conference on Mobile and Wireless Communications Networks 2003

This means that, under full loading, a significant proportion of FDD uplink bandwidth goes underused under multimedia usage conditions (even after taking different UL:DL power levels into account). For multimedia systems, assigning channels to TDD enables the spectrum to be better matched to the traffic load (mainly DL). Therefore TDD is more spectrally efficient, even after accounting for guard bands, than FDD under these typical asymmetric traffic conditions. This is illustrated in

Figure 6-7, assuming that TDD operators are UL/ DL time synchronised with an UL:DL ratio of 1:4 and that the system is dominated by DL traffic.

[36] “Asymmetric UMTS for Spectrum Efficient Asymmetric Services Delivery”, L. Vignali, F. Malavasi, D. Grandblaise, D. Lacroix-Penther, J-P Javaudin, Proc. of the 5th IFIP-TC6 International Conference on Mobile and Wireless Communications Networks 2003.

Figure 6-7: Comparison of spectrum allocation against spectrum utilisation under full loading for various example band plans



Source: PA analysis

6.6 Ecosystem/ scale economy/ innovation considerations

The scale of the 3GPP mobile ecosystem has enabled consumers to realise benefits through price, innovation and rapid deployment of technology and services. The success of an alternative technology to 3GPP may reduce scale among incumbents - but even if it does this may not materially affect economies of scale, and would not automatically lead to reduced benefits to users and would not necessarily harm innovation

6.6.1 Potential impact

Some industry participants express concern that allowing alternative technologies to 3GPP in the 2.6 GHz band may affect the beneficial effects of scale economies

The development of an integrated, standardised international market for mobile equipment and services has enabled the development of efficient sub-strata concentrating on:

- Design and development of technology
- Manufacturing of handsets and base station equipment
- Distribution of equipment across the world
- Provision of sales and service to consumers.

These sub-strata have developed to the extent that the price of mobile hardware and services has reduced significantly over time, economies of scale enabling consumers to benefit from lower producer prices passed on by operators.

Standardisation provides stability and scale for a range of industry participants to apply resources to innovation, confident in their ability to reach a large potential marketplace across a broad range of geographies. A common set of interfaces using standardised radio services can also support a broad range of service providers and application providers, targeting consumers with niche applications and services that address specific requirements. The speed of development and dissemination of GSM mobile technology can be argued to have resulted in large part from its ubiquity, uniformity and the ‘network effect’ that increased the value of the service to consumers as take-up increased.

The use of the 2.6 GHz band exclusively for 3GPP could be argued to be an extension of this structure, tending towards maximum operating efficiency through maximisation of economies of scale, driving innovation and enhancing benefits for consumers. Some industry participants may claim that this drive to scale and innovation is challenged by the introduction of *FDD/ TDD flexibility*. The resulting uncertainty could be regarded as discouraging scale economies, interoperability, competition and innovation.

6.6.2 Issue management

Flexibility is unlikely to have a material impact on economies of scale, and may benefit users by further stimulating competition and innovation

Established producers of 3GPP-oriented products and services could lose scale to an extent as a result of competition. But regulators need to consider whether competition will affect the incumbents’ ecosystem and volumes to the extent that innovation, competition and economies of scale, rather than scale itself, are adversely affected.

Flexibility could well enable the successful entry of new entrants, operating on a smaller scale at least initially. But any reduction in volumes among the 3GPP ecosystem would not automatically mean higher prices. The size of the established ecosystem is such that the impact on cost may well be marginal or even negligible for most producers. Even if producers find unit costs rising as they retreat from previously sustained levels of scale economy, the result might be a merger between two competing established sellers to regain critical scale rather than increasing prices to consumers.

Flexibility will not necessarily reduce the impetus to innovate and may drive innovation by requiring successful new entrants that rely on a technology variant to offer an innovative service to consumers and/ or better value for money. Flexibility may further stimulate innovation by providing more cost effective access to fast-moving Internet-based products and services, and may also provide a stimulus to new/ enhanced market segments, such as nomadic wireless broadband data services for ultra-mobile computers, smart phones and an increasing range of network-connected consumer electronics devices. A new technology variant could offer a platform for innovation that the incumbent platform may not support, and innovation on the new platform may 'spill over' onto the existing platform.

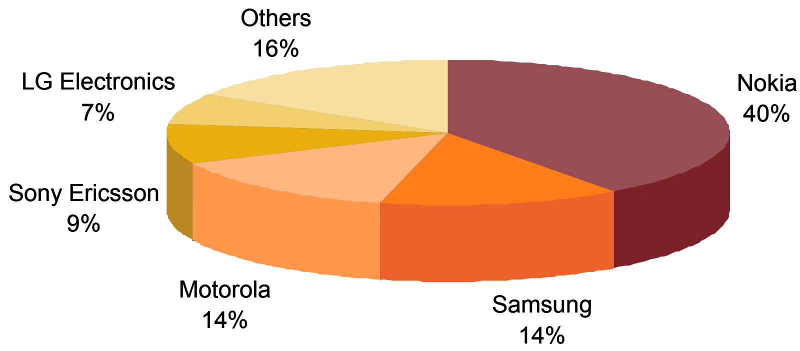
In addition, services are becoming more likely to be system independent, especially data services of relevance to the 2.6 GHz band. IP-based services and the mobile-enabled Internet offer users access to a broad range of content and applications. Many different types of terminal will have access to these services, enriching the consumer experience. It is in the industry's interests to encourage the 'network effect' and increase the penetration of services through interoperability. The regulator can create the conditions to encourage this, but it is up to industry participants to secure this environment by enabling interoperability that will enhance benefits for all.

TDD-based wireless broadband technologies, such as the TDD version of WiMAX, may come to market sooner than competitive technologies such as LTE. Introducing FDD/ TDD flexibility could enable TDD-based operators to achieve greater spectrum utility sooner, to the benefit of users. It could also, in general terms, have the consequence of encouraging greater innovation by established FDD operators and manufacturers as a competitive response to the challenge of TDD-based operators (as the advent of WiMAX technology, for example, appears to have had an effect in accelerating operator demands for the development of LTE).

It is also unlikely that an alternative and entirely separate industry ecosystem will develop in parallel as a result of competition between technologies using TDD and FDD. There may be significant synergies in manufacturing, distribution and retail of equipment and devices using TDD and FDD technologies that support the attainment and maintenance of scale economies (for example, WiMAX and LTE share some of the same underlying 'technology DNA', both being based on OFDMA).

Technology developers, manufacturers and operators are often not wedded to one technology or another. Many established vendors hope to defend market share and retain scale by operating across both TDD and FDD technologies. Of the top five global handset manufacturers, Nokia, Samsung, Motorola and LG are all involved in the manufacture of WiMAX handsets. In addition, Nokia Siemens Networks, Alcatel Lucent, Samsung, Motorola and Huawei are all manufacturing WiMAX networking equipment. Only Ericsson does not have a public strategy for entering the WiMAX market.

Figure 6-8: Global mobile phone shipments market shares 2007



Source: Strategy Analytics

Competition between technology variants can provide the impetus for radically different business models, applications and services, as well as the development of new terminal form factors and the integration of wireless connectivity into different types of consumer devices. In addition, competition may provide additional impetus to innovate for operators and manufacturers using incumbent technologies. All of this can increase benefits to users. Regulators will consider the possibility of missing out on these benefits when considering the arguments for economies of scale in the industry.

Our expectation, however, is that most regulators will not consider the issue of economies of scale as primary to their decision regarding the issue of FDD/ TDD flexibility. Flexibility in the allocation of spectrum between TDD and FDD modes does not create this issue. Rather, flexibility may increase the scope for TDD developers and operators to compete with FDD. The resulting increase in TDD-based activity is not likely to be material on a global scale in comparison with the manufacturing volumes of FDD equipment necessary to support scale economies, and may in reality drive innovation and competition.

6.7 Regulatory complexity / implementation burden

FDD/ TDD flexibility could increase the burden on regulators for both the assignment process and subsequent oversight of interference management – though adjustment and development of processes will be sufficient and early allocations across Europe will provide useful benchmarks

6.7.1 Potential impact

The regulatory processes required to manage the allocation process and subsequent interference issues may place greater burdens on regulators and require additional resources

The impact of *FDD/ TDD flexibility* could be argued to increase the burden on regulators. Some regulators could find it difficult to prioritise the necessary resources to deal with the implications of *FDD/ TDD flexibility*. Regulators may also find it counter-intuitive to be required, if necessary in some circumstances, to play a more active role in ensuring the successful practical operation of a market when the trend has been to withdraw from direct involvement.

This requirement for resources and involvement by the regulator relates to:

- Management of interference
- Management of flexible allocation of spectrum.

Interference is not a new issue for regulators to manage. Spectrum requires management by operators to ensure users' service is not interrupted or degraded by interference. Interference issues in the 3GPP world have been symmetrical, that is neighbouring operators are equally affected. This simplifies the requirement for regulation as it encourages both operators to reach agreement. The regulator can then act as an adjudicator of last resort, intervening only when the interested parties cannot reach agreement.

The introduction of flexible allocation of spectrum may affect this fine balance. It may lead to an increase in the occurrence and severity of interference between operators, both within a country and across international borders. Interference is likely to be asymmetric in its impact, which may create a disincentive among some operators to cooperate.

There may be a requirement on regulators to take a more proactive approach to resolving these issues:

- Before they arise by closely specifying the measure operators must take to counter interference, and actively testing that these measures are maintained
- After the fact, by highlighting a rapid and clear dispute resolution mechanism that provides operators with the confidence that issues affecting service will be resolved rapidly.

Either way, the 'light touch' approach that many regulators prefer may need to be modified on occasions.

In addition, the flexible allocation of spectrum, typically by auction, and the management of its reallocation, may require an increased level of input from regulators and, perhaps in some cases, some additional expert resources. Flexibility in spectrum allocation may require the management of a reasonably sophisticated auction to allow the market to influence the outcome in terms of the spectrum split between FDD and TDD. This may or may not be a significant change to the approach a given regulator has taken in the past, with implications for the skills and processes that the regulator would need to develop and deploy.

6.7.2 Issue management

FDD/ TDD flexibility does not generate fundamentally new issues for regulators – adjustment and development of processes will be sufficient and early allocations across Europe will provide useful benchmarks

The complexity of implementing *FDD/ TDD flexibility* should not be overstated. Our expectation is that most regulators implementing *FDD/ TDD flexibility* will not need to fundamentally change their approach, other than with respect to the spectrum allocation process itself.

Achieving *FDD/ TDD flexibility* in the 2.6 GHz band may require some adjustments to regulatory processes including the implementation of specific technical approaches to manage interference, but these measures are not fundamentally unfamiliar to regulators or unique to the implementation of *FDD/ TDD flexibility*. The approach of encouraging operators to resolve issues between themselves has worked effectively in the past and should be encouraged in the future to address the vast majority of circumstances.

The experience of regulators in larger countries with greater resources could also be more effectively used across Europe. Sharing of learning and techniques to implement *FDD/ TDD flexibility* could lessen the burden on smaller regulators with fewer resources. Pan-national regulatory and standards bodies may also have a role to play in acting as a 'clearing house' for approaches to manage flexibility.

As 2.6 GHz spectrum assignments progress across Europe, the models developed and deployed by regulators at the vanguard of the process will provide process templates and benchmarks for other regulators to analyse and tailor to their local circumstances.

6.8 Summary of potential management approaches for perceived issues

For convenience, Table 6-5 below summarises the management approaches discussed above in relation to each of the perceived issues identified with the implementation of *FDD/ TDD flexibility*.

Table 6-5: Summary of management approaches

Category	Perceived issue	Summary of potential management approaches
Interference	Adjacent channel interference arising from FDD/ TDD boundaries	Employ guard bands of appropriate width (usually 5 MHz) Mandate optimally specified technology-neutral emissions specifications (e.g. BEMs) Create a formally defined intermediation process for resolving operator disputes Inter-operator co-ordination based on: • Geographical co-location of FDD and TDD base stations • Separation of antennas (physically through vertical separation and also by using antenna directivity) • Appropriate cell channel allocation Technical approaches to minimise interference: • BS receivers with more stringent RF front-end filtering • Active Antenna Systems (AAS) in BS equipment • General improvements in transmitter/ receiver performance (ACLR/ACS)
	FDD terminal blocking interference from TDD services in regions with an 'alternative' band plan	Accept the resulting interference, given that: • The proportion of users and time for which such interference will be significant will be very small • Further, error correction and re-transmission techniques are likely to eliminate noticeable interference effects from a user perspective in the majority of circumstances
	Cross-border interference between operators	Apply the same techniques as for FDD/ TDD boundary adjacent channel interference to manage cross-border adjacent channel interference Adopt inter-region co-operation strategies to: • Ensure BS are appropriately sited relative to regional borders • Ensure channel re-use is optimised across borders to minimise co-channel interference Use lower power BS and antenna directivity in border areas to minimise cross-border power overspill
Regulatory protocols and implementation	The policy issue of diverging from the ECC Frequency Plan (ECC/DEC/(05)05)	There are precedents for an evolving interpretation of regulatory frameworks in the context of higher-order policy objectives The WAPECS initiative encourages service and technology neutrality

Category	Perceived issue	Summary of potential management approaches
		to promote efficient and effective use of spectrum There is a framework in place for making periodic policy reviews (ECC governance allows for three year reviews of decisions such as ECC/DEC/(05)05).
Efficiency, scale and innovation	Less efficient use of spectrum (increased guard band spectrum)	Given increasing market demand for asymmetric data services, efficiency gains from assigning more TDD channels are likely to offset losses from additional guard band spectrum
	Ecosystem / scale economy/ innovation considerations	Flexibility is unlikely to have a material impact on economies of scale for the established FDD industry and there are likely to be synergies between FDD and TDD-based products and services in any case. Users may benefit from further stimulation of competition, including the advancement of FDD-based technologies e.g. LTE and improved incumbent operator performance. Flexibility will not necessarily reduce the impetus to innovate and may further stimulate innovation by providing more cost-effective access to fast-moving internet-based products and services. Flexibility may also provide a stimulus to new/ enhanced market segments, such as nomadic wireless broadband data services.
Regulatory protocols and implementation	Increased regulatory complexity/ burden	FDD/ TDD flexibility does not generate fundamentally new issues for regulators – adjustment and development of processes will be sufficient and early allocations across Europe will provide useful benchmarks and process templates

Source: PA analysis *[vi/vi-(ii)]*

Appendix A: Summary of 2.6 GHz licensing status in key reference markets

This appendix summarises the regulatory position in Europe at the end of January 2008 with respect to licensing of the 2.6 GHz band and highlights the situation in four leading reference markets outside of Europe; Hong Kong, Japan, New Zealand and Singapore. This information has been drawn from consultation and licensing documents published by the regulators.

A.1 Europe

The Norwegian regulator has already carried out an auction of spectrum in the 2.6 GHz band and the Swedish regulator has published definite plans setting out its intentions for the band. The UK regulator Ofcom is soon to publish its final plans for the spectrum after a consultation period in which it set out its intentions for the band.

A.1.1 Norway

Local circumstances drove the decision of the NPT to opt for a flexible auction, but with an approach based on the ECC Frequency Plan (ECC/DEC/(05)05)

The Norwegian Post and Telecommunications Authority (NPT) was the first regulator in Europe to carry out a licensing event for the 2.50-2.69 GHz bands, in November 2007. The NPT offered 190 MHz of spectrum in the 2.6 GHz band. The licences were for periods of 14 years up to the end of 2022. The spectrum was allocated on a regional basis with the country split into 6 regions.

Technology and service neutrality

The NPT defined the licences as technology and service neutral, with the effect that the *"licensee may select the technology and service on which to base his or her use of the frequency band."*[37] The licences are tradable, enabling sale or lease of the spectrum.

The NPT did, however, introduce a caveat to the licences that would enable modifications to the conditions of the licences if CEPT's reply to the European Commission's requirement for a response to the WAPECS mandate resulted in harmonization of technical conditions in the 2.6 GHz band.[38]

[37] "Auction rules – allocation of licences in the frequency bands 2500-2690 MHz and 2010-2025 MHz", http://www.npt.no/portal/page/portal/PG_NPT_NO_EN/PAG_NPT_EN_HOME/...

[38] "Summary of answers to public consultation and updated proposals on technical conditions for the bands 2500-2690 MHz / 2010-2025 MHz", Post-og Teletilsynet, p.3

Spectrum cap

Bidders were allowed to submit bids for up to 90 MHz of spectrum in each region in the 2.6 GHz band, provided the sum total of the value of bids made in round 1 did not exceed the value of the guarantee submitted by the bidder. Following the completion of the auction, five operators had acquired spectrum.

Interference

The regional structure of the auction increased the possibility of interference between operators in different regions, using different technologies. The NPT proposed to manage this by:

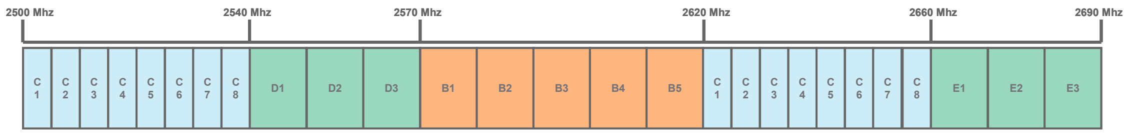
- Restricting TDD base station power for the lower 5 MHz channel of all TDD licences to 28dBm/ 1 MHz, with the expectation that neighbouring operators will agree on higher or lower power limits as appropriate
- Maximum permitted power levels – Unless agreed by operators in neighbouring regions, the field strength level on the border of a region must not exceed -122.5 dBW/m2 with a measuring bandwidth of 1 MHz.

Frequency allocation plan

The NPT split the 2.6 GHz band into four sub-bands made up of contiguous blocks, for each region:

- Sub-band B – 2570-2620 MHz – Five blocks of 10 MHz
- Sub-band C – 2500-2540 MHz and 2620-2660 MHz – Eight paired blocks of 2x5 MHz
- Sub-band D – 2540-2570 MHz – Three unpaired blocks of 10 MHz
- Sub-band E – 2660-2690 MHz – Three unpaired blocks of 10 MHz.

Figure A-1: Band plan used in the 2.6 GHz auction in Norway



Source: NPT

The amount of unpaired spectrum available is therefore potentially greater than that proposed in the ECC Frequency Plan (ECC/DEC/(05)05). The NPT introduced flexibility into the auction to respond to demand, with operators able to change the duplex method for sub-bands D and E. The NPT's reason for taking this approach was that *"it increases the flexibility for the market and that it is more in line with the market demand."*[39]

Results of the auction

The auction method achieved its aim of introducing a degree of flexibility that enabled operators to use two of the spectrum bands for either paired or unpaired spectrum, depending on demand. The

[39] "Summary of answers to public consultation and updated proposals on technical conditions for the bands 2500-2690 MHz / 2010-2025 MHz", Post-og Teletilsynet, p.1

unpaired spectrum in sub-bands D and E was paired together by Telenor nationally and Hafslund Telekom in Region 1.

The results of the auction were that:

- Sub-band B was acquired across all regions by Craig Wireless Systems Ltd
- Sub-band C was split between three operators:
  - Hafslund Telekom acquired C1 in region 1
  - Netcom acquired C1 in regions 2-6 and C2, C3 and C4
  - Telenor acquired C5-8
- Sub-band D was also split between three operators:
  - Telenor acquired D1 and D2
  - Hafslund Telekom acquired D3 in regions 1, 2 and 4
  - Arctic Telecom acquired D3 in regions 3, 5 and 6
- Sub-band E was acquired by four operators:
  - Telenor acquired E1 and E2
  - Hafslund Telekom acquired E3 in regions 1, 2, 3 and 5
  - Netcom acquired E3 in regions 4 and 6.

A.1.2 Sweden

The Swedish regulator has modified its approach to technology neutrality taking into account harmonisation with international standards

Sweden's telecoms regulator Post & Telestyrelsen (PTS) announced its plans for the band in January 2008.[40] It started the auction process in Q2 2008.

Technology and service neutrality

Point 1 of PTS spectrum policy states that:

"1. Licences to use radio transmitters shall be as technology and service-neutral as possible."[41]

The 2.6 GHz licences are therefore service neutral and, *"with certain restrictions"*, technology neutral. These restrictions refer to the DIR/99/05/EC which requires conformity of radio equipment and terminal equipment to standards recognised in the European Union. The PTS states that *"an essential requirement [for radio equipment] is that the equipment shall effectively utilise the radio spectrum and must not give rise to harmful interference."*[42]

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[40] "Open invitation to apply for licences for use of radio transmitters in the 2500-2690 MHz band", PTS, 17/03/08

[41] "PTS Spectrum Policy", PTS-VR-2006.2, Post & Telestyrelsen, 04/10/2006

[42] "Open invitation" PTS, 17/03/08, Appendix 1

PTS licence conditions enable the licence holder to select the technology and services used under the licence, and also subsequently change technology and use. However PTS states it can only authorise a change in technology *"if other licence holders are not subjected to harmful interference or accept that such interference arises. Licence holders applying for amended conditions must also, as necessary, use own frequencies as guard bands in order to prevent harmful interference."*[43]

Frequency plan

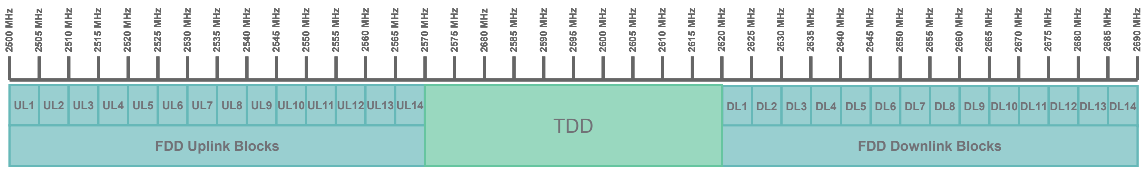
Point 8 of the PTS spectrum policy states that:

"8. Spectrum allocation shall be harmonised with other countries as far as possible".[44]

The frequency plan proposed by the PTS is in line with the ECC Frequency Plan (ECC/DEC/(05)05) recommendations for harmonised frequency usage across the European Union, as set out in the figure below, with:

- One block of 50 MHz of unpaired spectrum in the 2570-2620 MHz range, with the required use of TDD
- 14 blocks of 5 MHz of paired spectrum in the 2500-2570 MHz and 2620-2690 MHz ranges, with the required use of FDD.

Figure A-2: Band plan proposed for the 2.6 GHz auction in Sweden



Source: PTS

The decision to assign the 2570-2620 MHz band to TDD and the remainder for FDD was taken by the PTS because of its understanding of the intentions of manufacturers, driven by plans for international harmonisation, and the resulting impact on the Swedish market. The PTS states that:

"Equipment manufacturers are likely to use ECC decision ECC/DEC/(05)05 as their point of departure when developing equipment for the frequency band…[A]nother distribution between FDD and TDD would mean that use of this band would be made difficult. This is because a distribution between FDD and TDD that does not follow the decision of the ECC is very likely to mean that certain equipment (mainly FDD equipment) must be adapted to the Swedish market. This applies to both base station and terminal equipment."[45]

PTS believes base station issues could be overcome by using filters, but the terminal problem is more complex, and would require handsets to be adapted for the Swedish market. In addition the auction

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[43] "Open invitation" PTS, 17/03/08, p.8

[44] "PTS Spectrum Policy" PTS-VR-2006.2, Post & Telestyrelsen, 04/10/2006

[45] "Parts of an impact assessment concerning the National Post and Telecom Agency Regulations on licences to use radio transmitters in the 2500-2690 MHz band", Post & Telestyrelsen, 14/09/2007, p.4

process would be simplified if the frequency plan was in accordance with the ECC decision. The limits of technology neutrality are therefore, from the Swedish perspective, bounded by the requirement to harmonise as far as possible with international standards.

PTS arrived at the decision to licence the TDD spectrum in one block because of the likely interference issues within the TDD spectrum:

- In the 2570–2575 MHz frequency band, PTS is proposing to limit transmitter power
- The 2615-2620 MHz band is likely to have significant interference, limiting usage.

Therefore, in the opinion of PTS, only the core 40 MHz of the TDD spectrum will be usable. Splitting this between two operators that cannot coordinate usage would further reduce the usable frequency to 10 MHz. Parties interested in using the TDD frequencies stated that they would require a minimum of 30 MHz, and therefore PTS considered a single frequency block to be the most appropriate method of distributing this spectrum.

Spectrum cap

Bidders can bid for up to 140 MHz of spectrum out of the 190 MHz available. This limits the minimum number of operators to 2, and the maximum number to 15. A bidder could therefore purchase either:

- The whole 120 MHz of FDD spectrum; or
- The whole 50 MHz of TDD spectrum and part of the FDD spectrum.

Interference

PTS used CEPT draft report 19 as the basis for the licence conditions for 2.6 GHz. Its original interference specifications, as described in consultation documents were significantly more stringent. The licence conditions therefore reflect the latest consensus in managing power emissions.

Licence holders are able to deviate from these conditions if other affected licence holders approve of any changes.

A.1.3 United Kingdom

Ofcom is proposing a frequency plan and auction structure that enables allocation of paired and unpaired spectrum according to demand

Technology and service neutrality

Ofcom's overall strategy for spectrum *"is based on creating much more flexibility for users and reducing regulation.. Liberalisation allow[s] users to decide how spectrum should be used and for what*

- *progressive removal of restrictions on technology and usage*

- *replace with minimum technical conditions needed to prevent harmful interference".*[46]

This strategy of promoting service and technology neutrality has encouraged Ofcom to *"design the award process in such a way that the split between paired and unpaired spectrum can reflect the relative demand for each as revealed through the auction (rather than lock in a pre-determined split which could well turn out to be economically sub-optimal)."*[47]

Spectrum cap

Ofcom is proposing to adopt a spectrum cap that is equivalent to 80 MHz of unrestricted spectrum. Bidders can bid for paired or unpaired spectrum, or a combination of the two.

Interference

Ofcom has identified several differences between the BEM defined by SE42 in draft report 019 and its own formulations but it *"is satisfied that the BEMs contained in the CEPT Report are technically justified and provide a robust mechanism for managing interference between different licensees within the 2.6 GHz band. We therefore propose that they should be adopted as the basis for the technical licence conditions for the award of the 2.6 GHz band in the UK."*[48]

Frequency plan

Ofcom is proposing 5 MHz channelisation for both paired and unpaired spectrum. This approach is intended to enable an auction structure that is responsive to demand.

The proposed auction structure enables the development of an upper unpaired spectrum block in addition to a lower unpaired block based in the centre of band if unpaired spectrum is valued higher than paired spectrum. Each pair of 2x5 MHz blocks can be converted into two unpaired blocks. Additional unpaired spectrum over and above the minimum 50 MHz block is split into two separate and equal sized blocks:

- With one block contiguous to the lower end of the central block
- And one block at the upper end of the band.

The figure below describes Ofcom's proposed frequency plan for the 2.6 GHz band.

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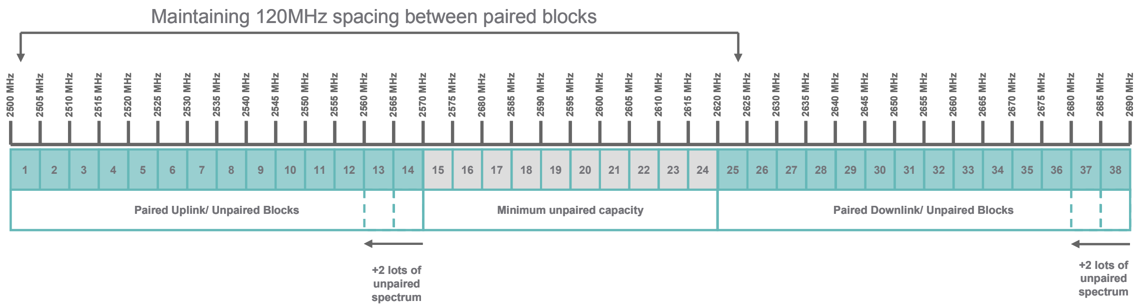
[46] "Consultation proposals for the award of the spectrum bands 2500-2690MHz, 2010-2025 MHz and 2290-2300MHz – Part 1", Ofcom, 8/02/2007, p.1

[47] "Award of available spectrum: 2500-2690 MHz, 2010-2025 MHz and 2290-2300 MHz: Consultation" Ofcom, 11/12/2006, p.5

[48] "Award of available spectrum: 2500-2690MHz & 2010-2025MHz: Consultation", Ofcom, 19/12/2007, p.33

Figure A-3: Ofcom's proposed frequency plan for the 2.6 GHz band



Source: Ofcom

A.2 Selected reference markets beyond Europe

A.2.1 Hong Kong

OFTA is planning a variation to the ECC Frequency Plan (ECC/DEC/(05)05), with 5 MHz blocks and the potential for more unpaired spectrum depending on local circumstances.

The Office of the Telecommunications Authority (OFTA), Hong Kong's regulatory body, has defined its policy towards spectrum for Broadband Wireless Access (BWA) services. OFTA has decided to auction spectrum in the 2.3–2.4 GHz band (termed the 2.3 GHz band) and the 2.50–2.69 GHz band (termed the 2.5 GHz band). The spectrum auction is scheduled for the fourth quarter of 2008.

Technology and service neutrality

OFTA has decided that there will be no restriction on standards or technologies, and no restriction on applications and services, beyond the requirement for technologies to conform to widely-recognised international standards. OFTA considers that, *"[a]s technology standards are rapidly evolving, [there is no need] to designate part of the spectrum for certain services for the reason that a particular technology is relatively more mature. Rather…deployment of BWA services shall conform to open standards and adhere to the technology neutrality principle. Indeed, the market, rather than the regulator, is more knowledgeable about the market environment including demands, trends and preferred choice of technologies and services."*[49]

The inclusion of WiMAX as one of the radio interface standards in the IMT-2000 family persuaded OFTA that WiMAX can *"coexist with other IMT-2000 standards in the spectrum identified for IMT, including the 2.3 GHz band and the 2.5 GHz band."*[50] OFTA has also amended the Hong Kong frequency plan to allocate 2.3 GHz and 2.5 GHz bands to fixed and/or mobile services.

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[49] "Proving Radio Spectrum for Broadband Wireless Access Services; Statement of the Telecommunications Authority", 03/12/2007, Para. 54, p.17

[50] "Proving Radio Spectrum for Broadband Wireless Access Services; Statement of the Telecommunications Authority", 03/12/2007, Para. 54, p.17 Para. 13, p.5

Spectrum cap

OFTA is planning that each operator will be assigned no more than six 5 MHz blocks of spectrum, or 30 MHz in total. This is regarded as *"technically sufficient for a BWA network to provide acceptable coverage and quality services…[W]hilst under-assignment would create technical difficulties to the operator, over-assignment would not be conducive to the efficient use of spectrum."*[51]

OFTA is therefore intending that the spectrum will be assigned to a minimum of six operators, with the actual number of licences determined by interest in the bid and the outcome of the auction rather than a 'command-and-control' approach.

Interference

OFTA expects that operators will deploy both TDD and FDD in the 2.5 GHz band, and proposes that guard blocks of 5 MHz may be required between the TDD and FDD blocks. It expects that *"licensees may settle [mutual interference] problems among themselves through technical coordination and deploy additional management measures, such as using the emission masks,"* and encourages operators to coordinate among themselves and agree on technical measures to be taken to minimise interference.[52] The TA mentioned it may issue guidelines or a code of practice requiring licensees to take reasonable measures to prevent interference.

Frequency allocation plan

OFTA intends to plan the 2.5 GHz band in line with the ECC Frequency Plan (ECC/DEC/(05)05). However there are cross-border interference issues that will need to be addressed:

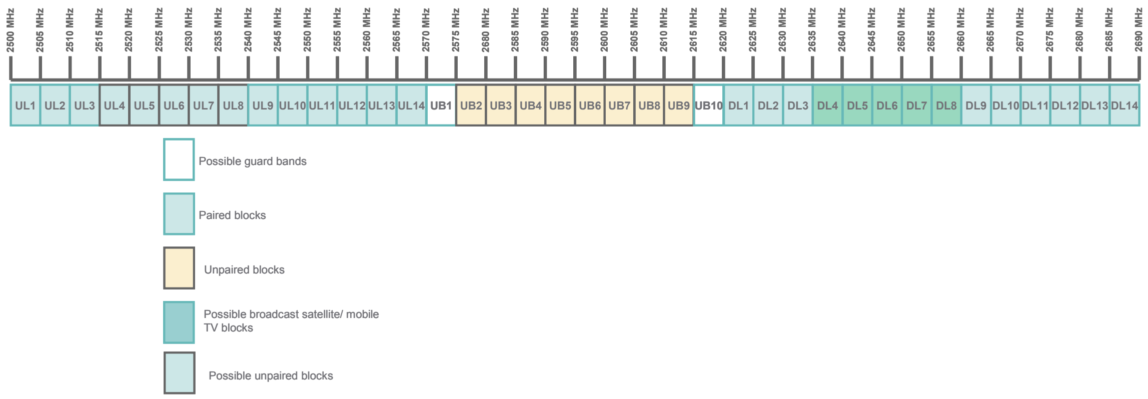
- The 2535 – 2599 MHz band is allocated for Microwave Multipoint Distribution System. OFTA plans to coordinate spectrum usage with the Guangdong authorities
- China is planning to launch the China Mobile Multimedia Broadcast satellite in 2008 for broadcast in the band sub-band 2635 – 2660 MHz.

OFTA recognises that adherence to the ECC Frequency Plan (ECC/DEC/(05)05) may not be fully achievable. The sub-band 2635–2660 MHz may also be deployed for other purposes in Hong Kong to coordinate with mainland usage. This would mean that TDD equipment would have to be deployed in the spectrum paired with 2635–2660 MHz. OFTA has published a tentative frequency plan that takes these points into account, and is dependent on the development of regulatory standards for satellite broadcast as set out in the figure below:

[51] Ibid. Para.18, p.9

[52] Ibid. Para. 42, p.14

Figure A-4: Proposed frequency plan for use in the 2.5 GHz band in Hong Kong



Source: OFTA

In summary, OFTA is developing a spectrum plan for:

- 190 MHz of spectrum in the 2.5 GHz band
- In 5 MHz blocks
- With 28 blocks of paired spectrum and 8 blocks of unpaired spectrum
- Unless 5 blocks are allocated to mobile TV broadcast, in which case there will be 18 blocks of paired spectrum and 11 blocks of unpaired spectrum.

A.2.2 Japan

Two blocks of unpaired spectrum were allocated in the 2.5 GHz band, with one winning bidder proposing to use WiMAX and the other a proprietary next-generation PHS technology

The Ministry of Internal Affairs and Communications (MIC) awarded spectrum in the 2.5 GHz band to Willcom and Wireless Broadband Planning in December 2007. The spectrum was awarded using a beauty contest approach, with four bidders competing for two licences.

Technology and service neutrality

The MIC offered two licences for use as national mobile service providers. The licences were allocated for use for high speed data access using third generation mobile technology. Bidders were not required to use a specified technology but their choice of technology formed one of the inputs into the assessment of each of the bidders. Willcom proposed using next generation PHS technology, while Wireless Broadband Planning proposed using WiMAX technology.

Spectrum cap

The two national mobile operators were allocated 30 MHz of spectrum each. Only two licences were available.

Interference

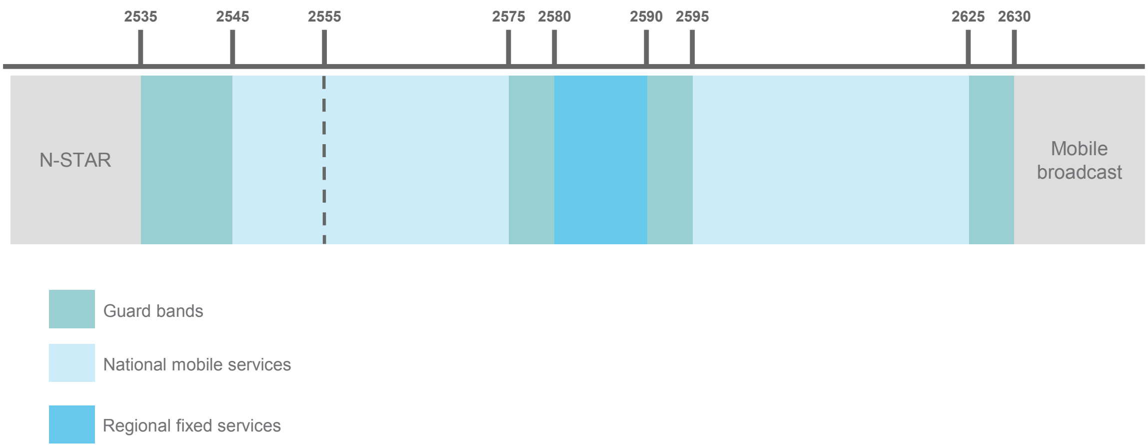
The MIC specified guard bands of:

- 10 MHz between N-STAR satellite mobile services and the operators with the lower 2545-2575 MHz sub-band
- 5 MHz bands between the national mobile services and the regional fixed service, and also between the national mobile operator operating between 2595-2625 MHz and mobile broadcast spectrum from 2630 MHz.

Frequency allocation plan

The MIC allocated two blocks of 30 MHz out of a total of 80 MHz in the sub-band 2545-2625 MHz to mobile services. The two blocks are separated by 20 MHz of spectrum, with two 5 MHz guard bands either side of a 10 MHz block. The 10 MHz block is allocated to regional government to be used for fixed wireless access services, using WiMAX or next generation PHS, with the aim of addressing the digital divide.

Figure A-5: Band plan for the 2.5 GHz spectrum in Japan



Source: MIC

The 10 MHz of spectrum between 2545-2555 MHz is occupied until the end of 2014.

All of the bidders for the spectrum were proposing technologies that required channelisation of 10 MHz.

A.2.3 New Zealand

The New Zealand approach reserved most blocks for unpaired spectrum, and opened up other blocks for either paired or unpaired spectrum

New Zealand's telecommunications regulator the Ministry of Economic Development (MED) carried out the auction for 145 MHz of spectrum in the 2.5 GHz to 2.69 GHz band in December 2007. The MED sold off six lots in the 2.6 GHz band in addition to two lots in the 2.3 GHz band. Six operators won the auction rights to the eight blocks.

Table A-1: Summary of the results of the New Zealand 2.3 GHz and 2.6 GHz auction

	2300-2335	2335-2370	2500-2520	2520-2540	2540-2575	2620-2640	2640-2660	2660-2690
Capacity MHz	35	35	20	20	35	20	20	30
Price NZD	593,333	650,000	405,000	456,000	670,000	373,000	450,000	450,000
Winner	Kordia Ltd	Woosh Wireless	Craig Wireless Systems	Telecom Leasing Ltd	Vodafone Mobile NZ	Craig Wireless Systems	Telecom Leasing ltd	Compass Communi-cations

Source: MED

Technology and service neutrality

The MED used an approach that favoured reserving four of the eight lots for unpaired spectrum, making them viable for TDD-based technologies such as the TDD version of WiMAX, and opening up the remaining four for either paired or unpaired spectrum.

Spectrum cap

The maximum amount any bidder could acquire in the auction was 40 MHz, meaning a minimum of five operators could purchase the spectrum.

Interference

The MED aims to manage interference by specifying power emissions. For each lot the management rights state that within 5 MHz of the lower boundary of the frequency, *"the maximum power of emissions permitted in accordance with that licence are not to exceed 5 dBW (e.i.r.p.) unless an agreement has been reached with the manager immediately adjacent to that lower boundary. Where an agreement has been reached with the manager immediately adjacent to that lower boundary, there is no limit on the maximum power of emissions permitted in accordance with that licence unless specifically limited by that agreement."*[53]

Frequency allocation plan

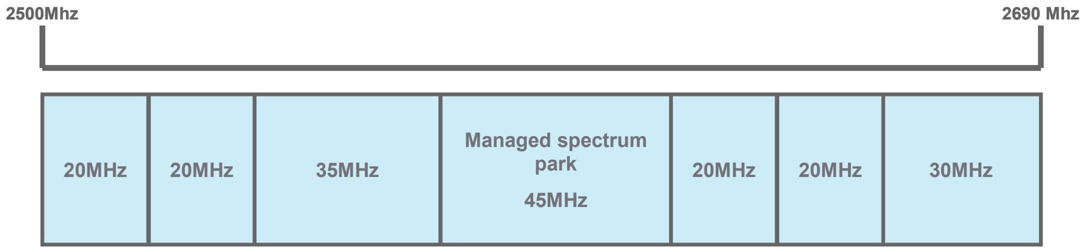
The frequency plan determined by the Ministry of Economic Development following consultation with the industry sought to balance:

- The aim of enabling, subject to market demand, the allocation of as much frequency as possible for TDD-based technologies, such as the TDD version of WiMAX, to support the rollout of wireless broadband services, therefore meeting the aims of government policy
- The possible requirement of the cellular mobile industry to use this spectrum for next generation services.

[53] "Radio Frequency Auction No. 9 Auction Catalogue", ISBN: 978-0-478-31608-7, Ministry of Economic Development, 02/11/2007

In addition the frequency plan had to take into account the requirement to provide Managed Spectrum Parks (MSP) for local wireless broadband operators and Maori interests. The figure below shows the frequency plan for the 2.6 GHz band.

Figure A-6: Frequency plan used in New Zealand



Source: MED

As a result, the restriction on bidders acquiring no more than 40 MHz of spectrum means that:

- The 2540-2575 MHz and 2660-2690 MHz blocks are appropriate for TDD
- The 2500-2520 MHz, 2520-2540 MHz, 2620-2640 MHz and 2640-2660 MHz blocks are appropriate for FDD, or if two contiguous blocks were acquired, TDD spectrum.

The plan was structured to encourage the deployment of wireless broadband technologies in order to develop broadband access in rural areas. It also ensured a degree of flexibility to enable New Zealand's two mobile network operators to compete for the spectrum required to provide wireless broadband services. It is worth noting that one of New Zealand's two mobile operators, Vodafone, chose to secure the 2540-2575 MHz block.

A.2.4 Singapore

The Singaporean band plan was formulated to minimise interference with neighbouring countries, and was technology and service neutral

Technology and service neutrality

Singapore's regulator the Info-Communications Development Authority (IDA) auctioned the majority of the 2.5 GHz band in 2005 for use as technology and service neutral wireless broadband spectrum. Following the issue of Singapore's 3G licences, the IDA committed not to release additional 3G spectrum until 2006. As a result, successful bidders were not able to use the spectrum for mobile services until 2006. Thereafter, bidders were able to use the spectrum for mobile in addition to "*stationary fixed*" and "*limited mobility*" services.

The spectrum is used under Singapore's Facilities-Based Operator (FBO) licence, and a Station/ Network Licence. The licences were therefore issued without a requirement limiting technology or service.

Spectrum cap

The auction rules stated that no bidder was able to bid for more than six lots of spectrum. Bidders related to Singapore Telecom and Starhub, Singapore's two fixed infrastructure operators, were not able to bid for more than four of the lots. This reflects the regulator's intentions to promote greater infrastructure-based competition.

Interference

The IDA required bidders to co-ordinate among themselves and with operators in neighbouring countries to avoid interference, and took the position that it would intervene only where operators were unable to resolve differences between themselves. The IDA did, however, issue technical guidelines to assist operators with their attempts to resolve issues:

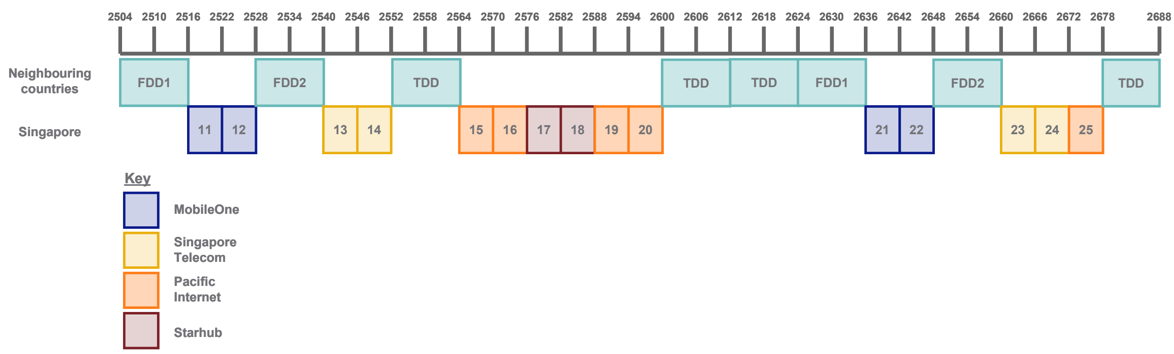
- Emission and attenuation – *"For base stations and mobile stations, the attenuation should be not less than 43 + 10 log (P) dB at the channel edge based on a resolution bandwidth of 1 MHz or greater"*[54]
- Signal strength – Limiting median field strength to a maximum 47 dBμV/m, measured at 1.5m above ground over the channel bandwidth.

The frequency allocation plan devised by the IDA took into account the band plans of neighbouring countries. The IDA auctioned frequencies that neighbouring countries were not using, and advised bidders of the use (either TDD or FDD) of adjacent frequencies in neighbouring countries. The frequency allocation plan below shows the allocations of neighbouring countries and the spectrum purchased by Singaporean bidders in the 2.5 GHz band.

Frequency allocation plan

The IDA allocated 15 blocks of spectrum in the 2.5 GHz band in blocks of 6 MHz. The auction process allowed each bidder to submit bids for up to six blocks, or four in the case of Singapore Telecom and Starhub. Each block was valued at between SGD450-550,000, except for block 25 which was valued at SGD269,000.

Figure A-7: Frequency plan for the 2.5 GHz band in Singapore



Source: IDA

[54] "Auction of Wireless Broadband Spectrum Rights: Information Memorandum", Schedule 2, IDA, 25/02/2005

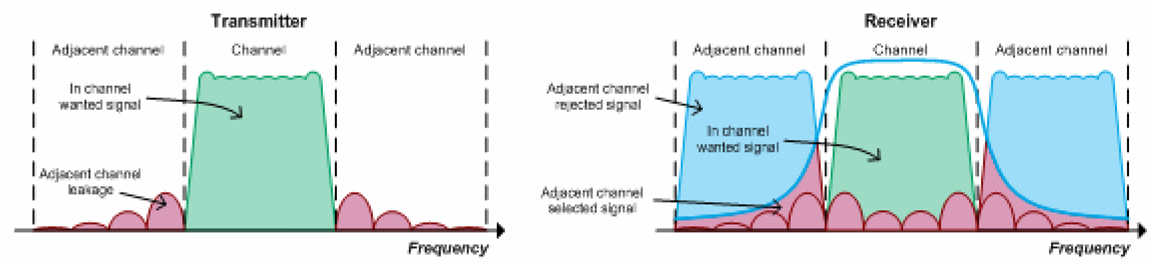
Appendix B: Technical overview of adjacent channel interference mechanisms

This appendix provides further supporting technical information on the adjacent channel interference mechanism.[55]

Adjacent channel interference is a combination of two factors (illustrated in the figure below):

- Leakage of power from a transmitter operating in an adjacent channel into the operating channel of a receiver. This is defined by Adjacent Channel Leakage Ratio (ACLR)
- Rejection by a receiver of power intentionally transmitted in adjacent channels. This is termed Adjacent Channel Selectivity (ACS): the ratio of the powers of adjacent channel interference to co-channel interference that result in the same Bit Error Rate (BER).

Figure B-1: Transmitter unwanted emissions and limited rejection at a receiver



Source: See 55

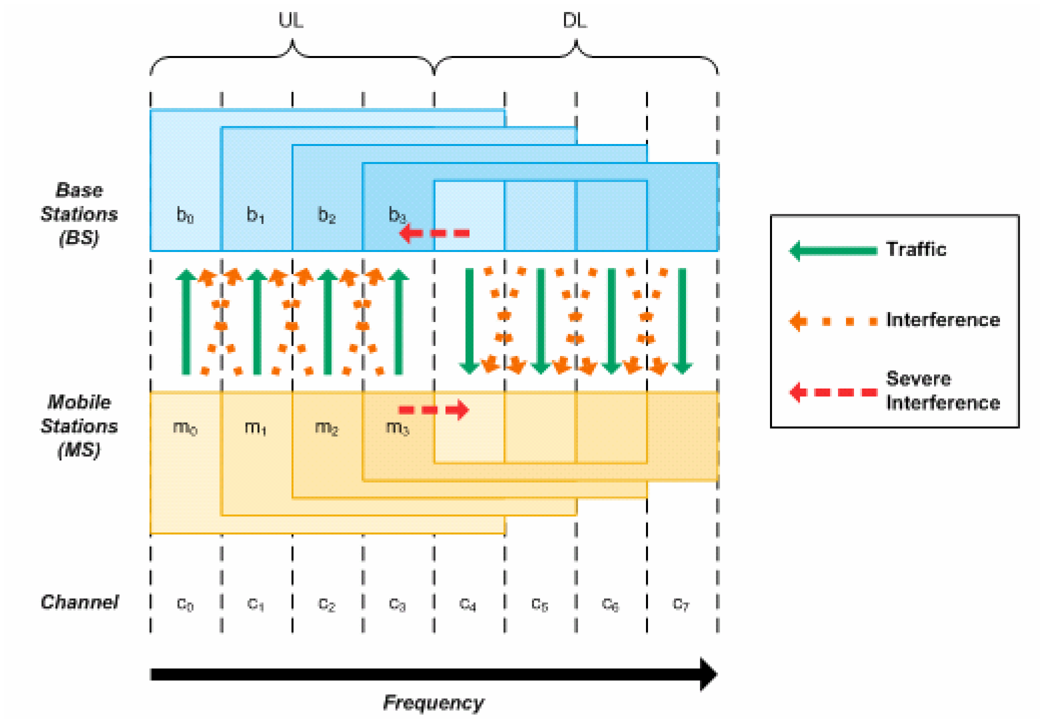
ACLR and ACS can be combined to give an Adjacent Channel Interference Ratio (ACIR) that characterises the entire link. This is defined as:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}$$

A band occupied by purely FDD channels has relatively little scope for intra-band cross-channel interference (see the figure below), as there is only one pair of up- and downlink channels which are adjacent in frequency. In practice, the uplink and downlink sub-bands are always separated by a large guard band to reduce interference due to this adjacency.

[55] “Service Recommendations to Support technology neutral allocations: FDD/ TDDFDD/ TDD Coexistence” WiMAX Forum, 10/04/2007

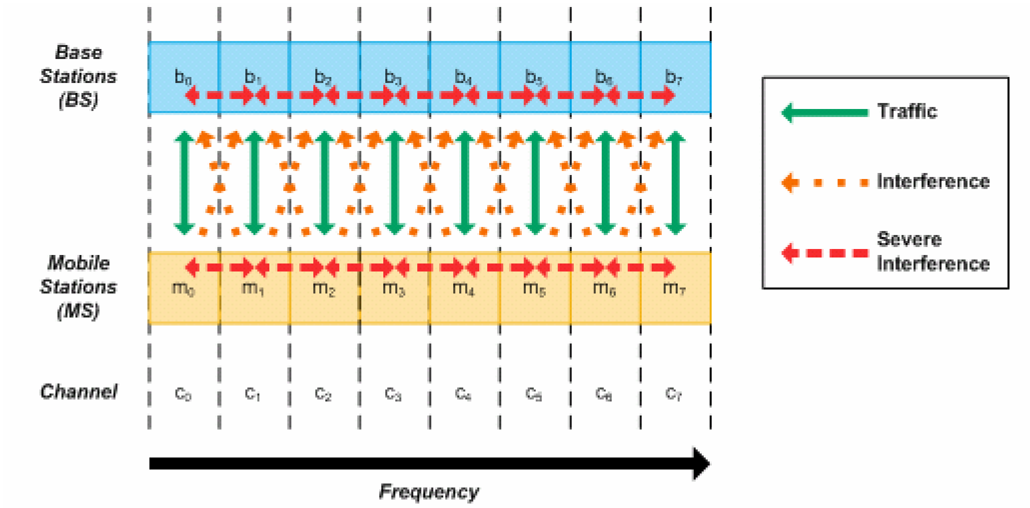
Figure B-2: Interference arising in a band occupied by solely FDD systems



Source: See 55

A band consisting entirely of TDD channels has more scope for intra-band cross-channel interference (see the figure below), as each channel is both an uplink and downlink at various points in time.

Figure B-3: Interference arising within a band occupied by solely TDD systems



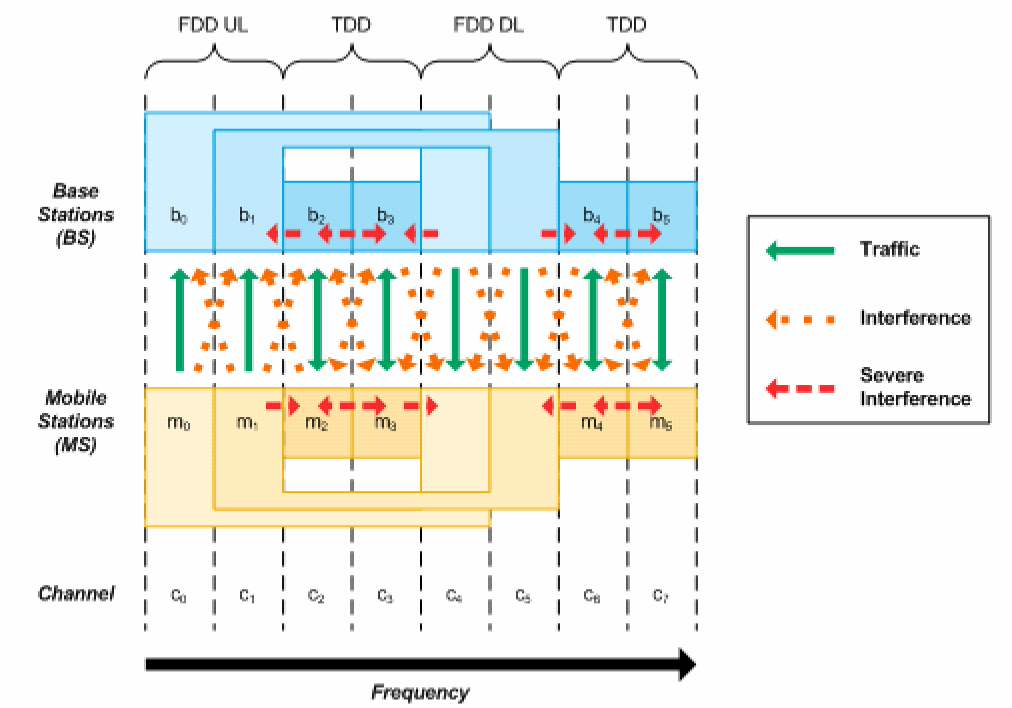
Source: See 55

The interference illustrated can be overcome by specifying guard bands between the TDD channels, improving the transmitter / receiver performance, or synchronising the timing of the TDD systems such that they all transmit / receive in tandem (this requires the uplink / downlink capacity ratio to be common between the TDD systems).

Adoption of a synchronised timing approach amongst TDD operators has been assumed for our main technical discussion.

The situation where a mixture of FDD and TDD technologies is employed is shown in the figure below. Notice now that FDD BS / TS operating in channels adjacent to TDD equipment suffer the equivalent interference to the FDD uplink / downlink boundary in an FDD system with no uplink / downlink guard band.

Figure B-4: Interference arising within a band occupied by a combination of FDD and TDD systems



Source: See 55

Appendix C: Emission specifications for interference management in a technology neutral environment

This appendix discusses several methods for defining emission specifications that are compatible with technology neutrality. Such specifications are a necessary condition of spectrum licensing to prevent interference.

The Draft CEPT Report 019[56], Section 4.4, provides a good basis for exploring such methods, and this appendix draws on the report, particularly Section 4.4.

The conventional method for defining emission specifications involves direct comparison of the exact technical parameters of the transmitter and receiver of two pieces of communications equipment to establish their maximum transmitted emissions whilst maintaining acceptable levels of interference. This is completely inapplicable to a technology neutral environment where the nature of the equipment to be used in the allocated spectrum is unknown.

This is the motivation for development of the alternative techniques as described below:

- Block edge masks (BEMs)
- Power Flux Density (PFD) masks
- Power Spectral Density (PSD) masks.

Each of the techniques discussed aims to output a set of Spectrum Usage Rights (SURs). These essentially define 'rights' to emit RF within defined parameters that are not referenced to a specific technology.

C.1 Block Edge Masks (BEMs)

The principle of BEMs is to specify an emission mask for an entire block of spectrum assigned to a given operator, in terms of allowable emissions both within the block, and outside the block, up to the band edge. No consideration is given of the required performance relating to individual channels within a block; it is in the interests of the operator to essentially 'self regulate' these (to prevent interference amongst their own equipment).

[56] "Draft CEPT Report 019: Draft 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", Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), December 2007

BEM emission masks are based on the output of a single transmitter: no consideration is given to the aggregate power resulting from multiple transmitters. Therefore caution is required when specifying BEMs for spectrum where the transmitter density will be variable.

BEMs are developed based on the worst-case assumptions of the precise technologies likely to be deployed within a band. The parameters of any alternative deployed technology must still satisfy the BEM.

Similarly, the BEM characteristics will be derived to give interference-free operation to an assumed receiver specification. If alternative receivers with lower performance are deployed they cannot be guaranteed not to be victims of interference.

At the same time, a BEM will not necessarily allow operation of the assumed technology adjacent to the block edge at maximum power. Equipment residing in block edge channels may have to operate at reduced power or not occupy spectrum right up to the block edge.

When equipment is deployed adhering to a BEM, any equipment-specific standards (e.g. R&TTE directives) still apply, and may be more stringent than the BEM.

There are two methods for specifying a BEM:

- **Transmit power** – this specifies a limit mask for transmit power or power spectral density from any given transmitter. The maximum expected interference can only be deduced from a limit defined in this way if the characteristics of the transmit antenna are known.
- **Equivalent Isotropically Radiated Power (EIRP)** – this is as the transmit power / power spectral density based specification, but transmit antenna characteristics are taken into account. The EIRP is the power that would be required to give an isotropic antenna the same output power density as the peak output power density of the real antenna. Thus antenna characteristics are accounted for.

C.2 Aggregate Power Flux Density (PFD)

In contrast to the BEM approach, the aggregate PFD approach sets limits on the amount of RF energy present at a receiver. This implies that multiple transmitters can contribute. PFD is measured in dBW / m2 / MHz and is often specified not to be exceeded at more than X% of locations in a given area Y km2.

This approach is similar to that conventionally taken to define interference at borders.

A major disadvantage of this technique is that it is difficult to account for terminal stations. It also does not account for differences between FDD and TDD.

C.3 Aggregate Power Spectral Density (PSD) Transmitter Masks

Using this technique PSD contributions (dBW / Hz) are aggregated by all transmitters over a specific area. Each contribution to the aggregation is typically assessed prior to the application of antenna gain, with the anticipation that this will have no overall affect over the area in question. Correction factors are then introduced to account for antenna parameters which do have a net effect over the measurement area.

This technique also suffers from the difficulties in accounting for terminal stations and TDD / FDD experienced by the aggregate power flux density (PFD) method.

C.4 Choosing an appropriate emission specification

A summary of the positive and negative aspects of the emission specifications described above is given in the table below.

Table C-1: Positive and negative aspects of various SUR definition methodologies

Definition type	Positives	Negatives
BEM	Easy to apply, test.[57] Allows complete flexibility within blocks.[58] Similar to conventional methods[58]	Still based on a particular candidate technology.[58] No account for transmitter density.[58]
Aggregate PFD	Aggregate PFD directly related to likely level of interference.[58] No reference to any particular technology.[58]	Long measurement time to account for traffic / ducting.[58] Can allow high power 'spots' if Y% of locations in an area can exceed the specified PFD.[59]
Aggregate PSD	Accounts for transmitter density. [58]	Difficult to account for terminals as it is unknown how many are in a given area. [58]

Source: PA analysis

[57] "Draft CEPT Report 019: Draft 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", Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), December 2007

[58] "BT Response to the Ofcom Consultation on Award of Available Spectrum: 2500-2690MHz, 2010-2025MHz and 2290-2300MHz", BT, 9 March 2007

[59] "Orange response to Ofcom consultation on 'Award of available spectrum: 2500-2690 MHz, 2010-2025 MHz and 2290-2300 MHz", Orange, 8 March 2007

Overall BEMs provide a good balance between allowing technology neutrality and being simple to implement and enforce. The other two techniques (aggregate PFD and PSD) have technical shortcomings and are not yet well proven in the spectrum marketplace.[59]

Appendix D: Additional discussion of FDD downlink use for the 2570 to 2620 MHz sub-band

This appendix provides additional information concerning potential use of the 2570–2620 MHz sub-band for FDD downlink channels paired with FDD uplink channels outside the 2.6 GHz band

D.1 ECC Frequency Plan (ECC/DEC/(05)05) Options

As already outlined in Section 3.1, the ECC Frequency Plan (ECC/DEC/(05)05) provides two different options for the centre 50 MHz of the 2.6 GHz band. These are:

- Use for TDD channels
- Use for FDD downlink channels paired with an FDD uplink which is outside of the 2.6 GHz band .

Figure D-1: ECC Frequency Plan (ECC/DEC/(05)05) – TDD option

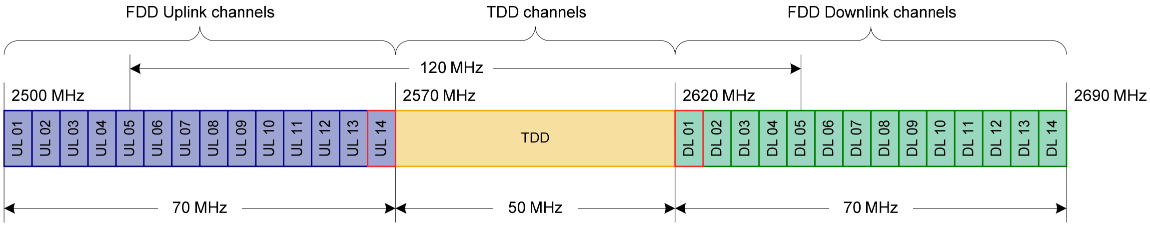
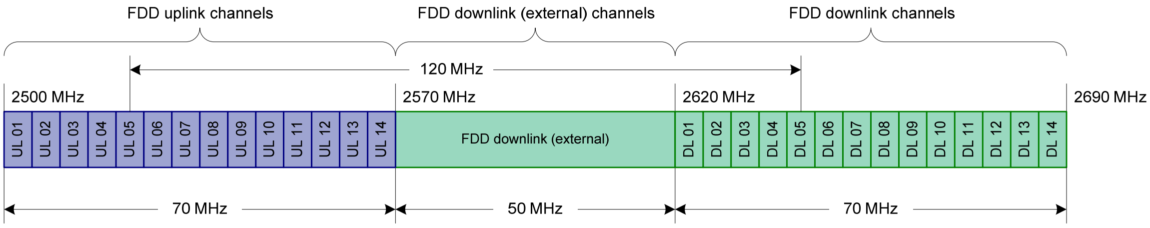


Figure D-2: ECC Frequency Plan (ECC/DEC/(05)05) – FDD downlink (external) option



Adoption of the latter of these options in a region would clearly preclude the introduction of TDD systems in the 2.6 GHz band in that region.

Source: ECC/DEC(05)05

D.2 Impact on harmonisation

A major drawback of having these two options present in the ECC Frequency Plan (ECC/DEC/(05)05) is that if different regions choose differently between the two options, many of the perceived effects of having a non-harmonised frequency plan become applicable:

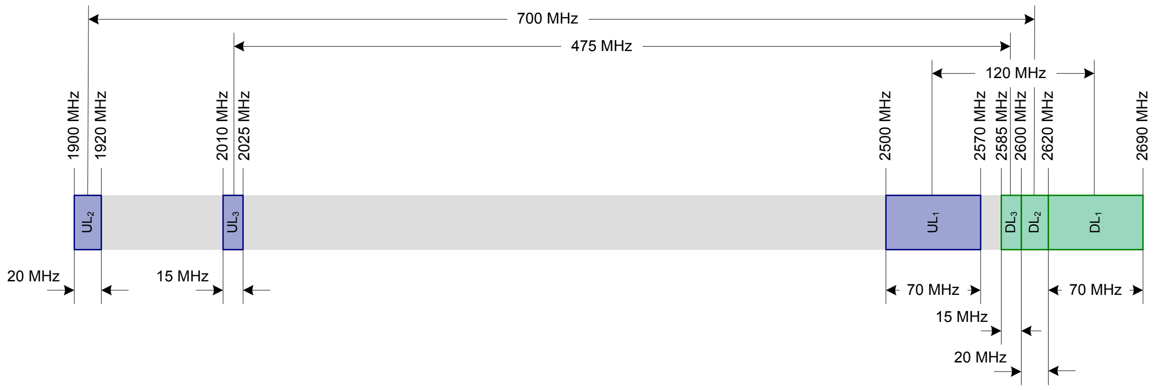
- **Denial of service on roaming** – a TDD terminal that is designed to only operate in the 2570 to 2620 MHz sub-band will not have any service available upon roaming to a region which has chosen the FDD downlink (external) option.
- **Terminal interference** – if the RF receiver front end of FDD terminals is designed to accommodate the entire potential downlink frequency range from 2570 – 2690 MHz, they will be susceptible to interference from TDD terminals when operating in regions which have adopted the TDD ECC Frequency Plan (ECC/DEC/(05)05). The mechanisms for this are the same as those described in Section 6.2
- **Cross border interference** – if a pair of neighbouring regions adopt the TDD and FDD downlink (external) ECC Frequency Plans respectively, users in the region that has adopted FDD downlink (external) ECC Frequency Plan may experience interference from TDD base stations and terminals in the neighbouring TDD ECC Frequency Plan region. The mechanism for this is discussed in Section 6.3.

D.3 External uplink spectrum allocation

To maintain harmonisation across those regions in Europe where the FDD downlink (external) option was selected for a 2.6 GHz band plan, common uplink spectrum would be required in an alternative band. This is not defined in ECC/DEC/(05)05 along with the ECC 2.6 GHz Frequency Plan. However, there is a later ECC decision, ECC/DEC/(06)01[60], which does suggest potential uplink frequencies for pairing with the downlink (external) allocation.

ECC/DEC/(06)01 defines 1900-1920 MHz and 2010-2025 MHz as either TDD or FDD uplink. If the FDD uplink option is chosen for these frequencies, the decision does not state that they should be paired with downlink frequencies in the 2.6 GHz band. However, this is clearly the intent of the ECC as evidenced by their request to 3GPP to develop standards with the pairings illustrated in the figure below.

Figure D-3: ECC FDD uplink / downlink pairings



Source: ECC/DEC/(06)01

[60] (ECC/DEC/(06)01): ECC Decision of 24 March 2006 on the harmonised utilisation of spectrum for terrestrial IMT-2000/UMTS systems operating within the bands 1900 - 1980MHz, 2010 - 2025MHz and 2110 - 2170MHz, Electronic Communications Committee

This request can be found in 3GPP document RP-050566[61]:

"ECC PT1 therefore formally requests 3GPP:

1. *to develop, as soon as possible, specifications for FDD uplink use in the bands 2010 – 2025 MHz and/or 1900 – 1920 MHz paired with a potential downlink in the band 2570 – 2620 MHz.*

2. *to give feedback on the feasibility of the current ECC PT1 working assumption to pair 1900 – 1920 MHz with 2600 – 2620 MHz, and to pair 2010 – 2025 MHz with 2585 – 2600 MHz."*

Interestingly, the 3GPP has not acted upon this request to standardise on the above channel pairings. This suggests that the channel pairings are not favoured by the traditional FDD proponents.

D.4 Issues introduced by ECC external pairing frequencies

The adoption of pairing frequencies as illustrated in the figure above itself introduces some negative issues.

It can be seen that this allocation leaves the 15 MHz between 2570 and 2585 MHz unallocated, effectively acting as an uplink / downlink guard band. This is equivalent to three 5 MHz channels. This is a similar level of allocation inefficiency as having two separate TDD sub-bands.

The pairs of uplink and downlink channels are rather narrow for the deployment of BWA services. For example, a 20 MHz LTE channel could not be accommodated in the 15 MHz wide pairing.

The uplink / downlink spacing does not adhere to the 120 MHz mandated for the rest of the ECC Frequency Plan (ECC/DEC/(05)05). This may have a negative effect on the sharing of components between the transmit and receive chains of terminals, leading to larger / higher cost terminals.

The uplink / downlink spacings themselves are rather large; 475 and 700 MHz are likely to make design of an effective antenna for both transmit and receive problematic.

[61] RP-050566: Formal request by ECC PT1 to 3GPP to develop specifications for FDD uplink use in the bands 2010 – 2025MHz and/or 1900 – 1920 MHz paired with a potential downlink in the band 2570 – 2620MHz, Electronic Communications Committee PT1, 15 September 2005

Appendix E: Additional discussion of frequency plan channelisation considerations

This appendix provides supporting information concerning channelisation arrangements for the 2.6 GHz band.

E.1 Channelisation defined in the ECC Frequency Plan (ECC/DEC/(05)05)

ECC/DEC/(05)05 in defining the ECC Frequency Plan mandates that *"assigned [frequency] blocks shall be in multiple[s] of 5.0 MHz"*. This seems appropriate as 5 MHz is small enough to allow a standard UTRA air interface, whilst 10 or 20 MHz blocks could be assigned for other candidate technologies such as LTE or WiMAX.

E.2 Granularity

Using larger block sizes invariably places greater restriction on the available number of permutations of spectrum assignments to operators. This will have the effect of complicating any auction or other allocation process, and possibly increasing the amount of spectrum that remains unallocated (due to gaps as large blocks are fitted into an allocation). The severity of this complication will vary depending on the number of operators and duplexing technologies (i.e. TDD and FDD) competing for spectrum. However, provided spectrum allocation methods are appropriately designed, this additional complication is unlikely to have a significant adverse effect on the allocation outcome.

The use of 10 MHz channels does not preclude the use of 5 MHz Guard bands – i.e. the system can remain on a 5 MHz raster, with 'bundled' blocks of 10 MHz offered at auction or arranged later by successful bidders.

E.3 Emission specifications

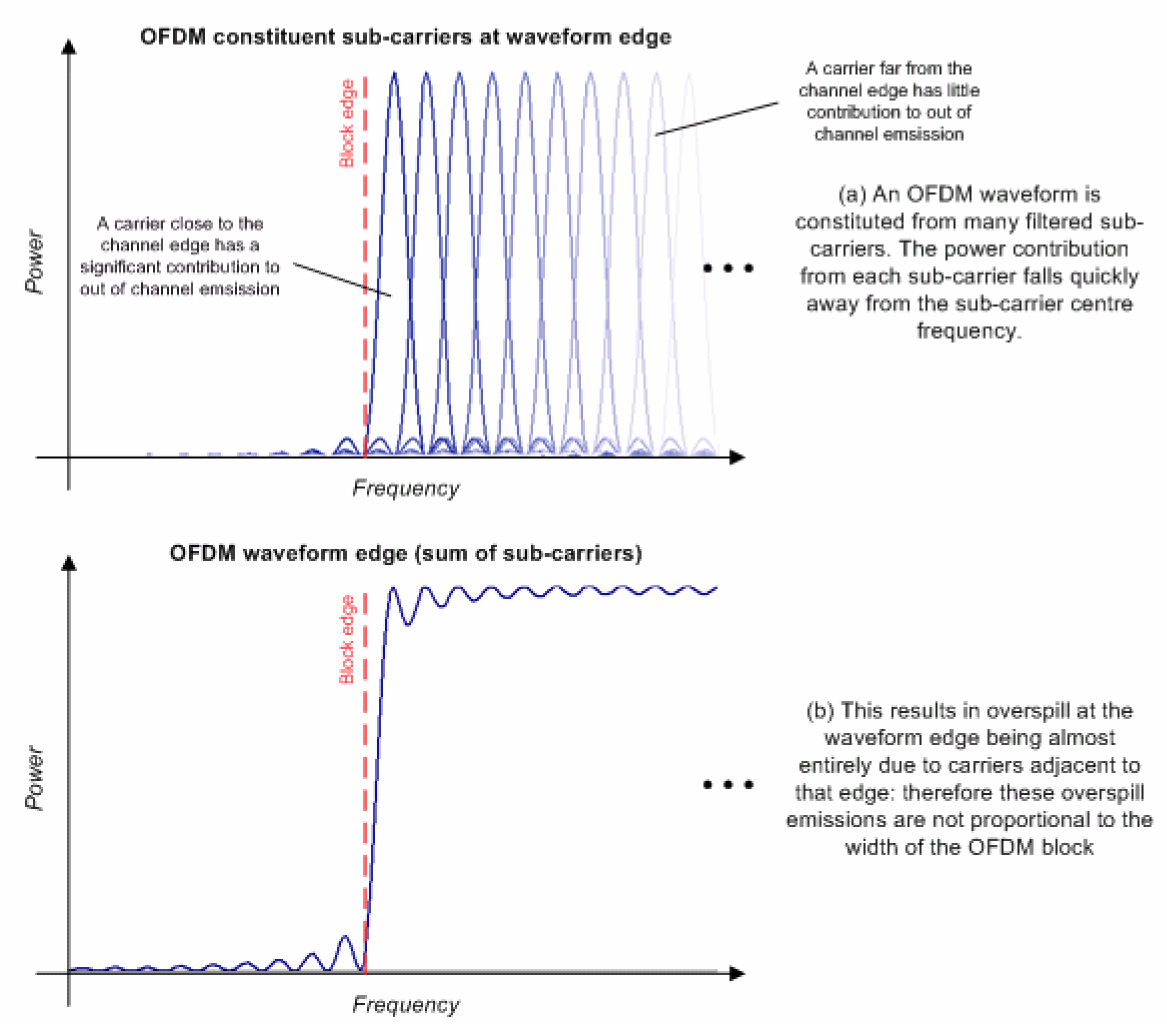
Technology neutrality can be supported by the adoption of maximally flexible emission specifications. These can be designed to not only be technology neutral, but also accommodate channelisation flexibility.

Channelisation flexibility is much easier to accommodate if emissions outside of the wanted channel are close to being independent of channel width. Such emissions are a result of two sources: -

- Finite filter roll-off applied to wanted signal allowing some direct emissions beyond the channel edge
- Out-of-channel emissions emanating from non-linear components such as the power amplifier

Considering specifically OFDM systems, which are likely to be the primary occupants of the 2.6 GHz band, the first of these is likely to be largely independent of block width. As illustrated in the figure below, linear emissions outside of a block edge for OFDM systems are likely to be primarily due to a small number of sub-carriers close to the block edge. However, unwanted emissions due to for example, a non-linear power amplifier, may not follow this relationship.

Figure E-1: Illustrative contribution from sub-carriers to OFDM overspill at waveform edge



Source: PA analysis

Retaining a 5 MHz view of emission boundaries will preserve the option of 5 MHz guard bands, while leaving implementation aspects to the operators/manufacturers.

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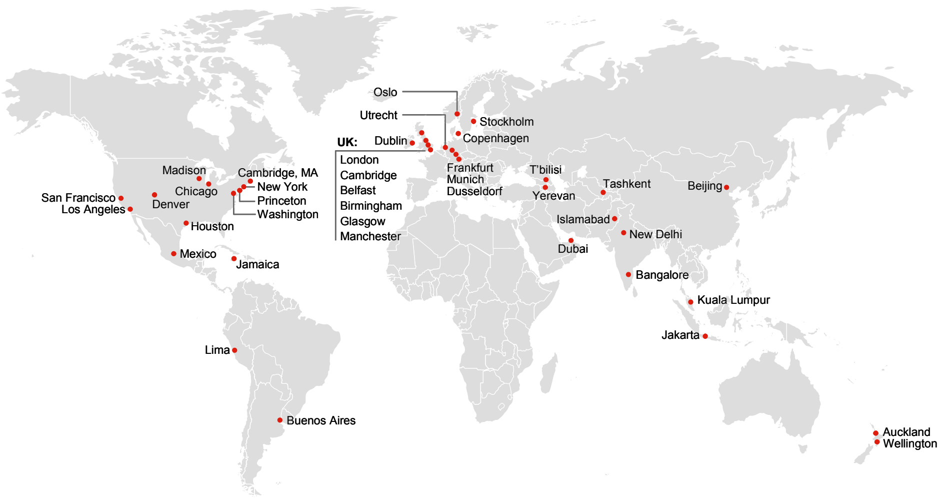

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