Allocation options for selected bands

410-415 MHz & 420-425 MHz;
872-876 MHz & 917-921 MHz;
2010-2025 MHz;
and 2290-2302 MHz

Final report for Ofcom

Prepared by DotEcon
and Analysys Mason Group

February 2005

Contents

Tables & Figures

Executive Summary

DotEcon and Analysys Mason Group have prepared this report as a summary of their study for Ofcom on allocation and assignment options for available spectrum in four bands:

- ***410-415 & 420-425 MHz.*** This band consists of 2 x 4MHz with 10MHz duplex spacing, which is currently fragmented across these two 5 MHz blocks. The spectrum has been reclaimed from the Dolphin TETRA network, which closed in 2004. Use of this spectrum is currently by arrangement with the MoD, and is subject to some geographic restrictions.
- ***872-876 & 917-921 MHz.*** This band consists of 2 x 4MHz of contiguous spectrum with a 45 MHz duplex spacing, available nationwide. This spectrum was previously allocated for TETRA2 but was never used.
- ***2010-2025 MHz.*** This band consists of 15 MHz of contiguous spectrum, including guard bands at either end, available nationwide. The spectrum is potentially available across Europe, and is part of the set of core 3G bands. It is currently allocated for unlicensed IMT-2000 TDD usage, although Ofcom intends to reallocate it for licensed use.
- ***2290-2302 MHz.*** This band consists of 12 MHz of contiguous spectrum, available nationwide, most of it having been released by the MoD. Availability is specific to the United Kingdom. The spectrum adjoins the 2302-2310 MHz band, which is currently used by emergency services but is earmarked for eventual release for public use.

Our approach

The study consisted of two phases:

- *Market assessment*. The objectives of this phase were to identify constraints on the use of the available spectrum; determine possible uses; understand potential sources of demand for the spectrum; assess the value and viability of the leading candidate uses; and analyse their competitive implications. As part of this phase, we interviewed 41 'stakeholder' organisations, including potential users, band managers, equipment manufacturers and financial institutions.
- *Assignment options*. The objective of this phase was to draw up recommendations for the assignment of available spectrum in light of the market assessment findings. Specifically, we have made recommendations for the packaging of primary usage rights, the scope for using auctions, and the format and timing of the assignment process. We do not consider the detailed implementation of the proposed assignment methods.

In developing our recommendations on allocation and assignment options, we were guided by Ofcom's own policy guidelines as described in the

Spectrum Framework Review (SFR). Our study also builds on the initial assessment of assignment options for the four bands in Ofcom's SFR Implementation Plan (SFRIP).

Ofcom's general approach to spectrum management is to allow the market to determine allocation (uses) and assignment (users), whenever possible. Thus, spectrum usage rights should, as far as possible, be free of technology and usage constraints, and be tradable in the secondary market. Further, primary assignment should normally be by auction, unless there are compelling reasons to believe that market mechanisms will not deliver an efficient outcome that is in the public interest.

410-415 & 420-425 MHz

Key findings

Demand for this spectrum is for private mobile radio (PMR), public access mobile radio (PAMR) and compatible uses, from both public and private sector users. We found no evidence of demand for deployment of national mobile/broadband systems.

Most potential users expressed concern about the impact of MoD use of this spectrum, in particular the extent of coordination requirements with the MoD radar installation at Fylingdales. Our discussions with Ofcom suggest that actual restrictions are less onerous than is widely supposed; clarifying this issue should solidify business cases for this spectrum.

The spectrum could either be made available through national licences or transmitter-based licensing. National licences would be most appropriate for band managers or wireless broadband systems, whereas transmitter licences would be more appropriate for direct licensing of PMR/PAMR use. Although we have identified PMR/PAMR as the main source of demand at present, this could change over time. Therefore, ideally the licensing systems should be able to accommodate all these types of uses, and allow for future changes through the secondary market.

Unfortunately, there is no single approach to the design of licensing that could easily accommodate both national and transmitter-based demand and allow market testing of which is most valuable. In particular, PMR/PAMR users are not likely to be able to coordinate by themselves their disparate demands in order to acquire a national licence. Similarly, a national or regional mobile operator would find it difficult to acquire the necessary local licences to offer contiguous service. There may be considerable limits to the ability of secondary market to switch between these various uses given the large numbers of users and/or licences involved.

National licences would be suitable for assignment by a simple auction. However, with transmitter licences, any unitary national auction system that allocated all spectrum in a single process and respected the full range of constraints owing both to interference between neighbouring users and with Fylingdales would be prohibitively complex. First come first served (FCFS) could be used as a simpler alternative, but AIP would be needed to choke off

demand in hot spots. However, even with AIP, FCFS is a poor tool for distinguishing between competing demands as there is little information available to determine the level of AIP, which might need to vary significantly from location to location. Therefore, there is a possible role for using simple auctions, which would be much easier to implement than a unitary national auction, to resolve competing demands in hot spots.

Band managers could have a useful role for this band in coordinating large numbers of users (thereby reducing transactions costs in the secondary market) and assisting in management of the interference constraints due to Fylingdales. Our modelling suggests that the private band management model is viable, with certain caveats over the need to ensure that end users be willing to acquire spectrum from the band manager. However, we found limited evidence of private sector interest in developing a band management business at present. A number of interested parties commented that there was a need for more clarity about how band management might work.

Having a single band manager may raise competition concerns, owing to the relative scarcity of spectrum currently available for digital PMR. A solution may be to assign spectrum to more than one band manager, which our modelling suggests may be a viable option. However, the possible need to reserve some spectrum for public safety use could limit availability of spectrum for private band management and possibly make competing band managers infeasible. In the event that only one band manager emerged, there are various powers open to Ofcom to address competition concerns (the Competition Act, Communications Act, Enterprise Act and spectrum management powers).

Recommendations

It is desirable to make this spectrum available quickly to PMR and compatible uses, to meet current demand from both the public and private sector. It is therefore important that the process that determines assignment reflects the value of spectrum to PMR/PAMR users. On this basis, we have identified two possible ways forward:

- *Option 1: Transmitter licensing*. The spectrum could be licensed by transmitter using a FCFS basis, with either geographically differentiated AIP to choke off excess demand or, if possible, a sealed-bid auction element to resolve competing demands in hot-spot areas. Although it is possible to envisage a unitary auction mechanism to resolve competing demands at a national level (including the trade-offs resulting from the interference constraint owing to Fylingdales being essentially national), we have rejected this as being too costly and complex relative to the potential efficiency gains.

  Setting AIP at a uniform national level to choke off excess demand in hot spots would mean that the price would be too high elsewhere. Therefore, if used, AIP would need to be geographically differentiated. Nevertheless, it might still be difficult to avoid excess demand whilst not choking off demand inefficiently, given that demand is difficult to forecast and likely to vary from place to place. A backup solution might

be to use a lottery to resolve competing demands where AIP failed to do so, although this may lead to windfall gains for some users.

A more efficient alternative would be to integrate an auction element into the process by inviting potential users to submit sealed bids alongside transmitter requests. This would be a hybrid system where auctions would operate independently at each hot spot where there was excess demand, but otherwise FCFS would be used. In order to operate independent auctions, it would be necessary to allocate the Fylingdales interference budget to each hot spot. Such a system would not be fully efficient as trade-offs between areas in meeting the Fylingdales interference constraint would not be considered. Nevertheless, this is a reasonable simplification that would produce close to efficient results and would not be unduly complex.

- *Option 2: National licence(s).* Ofcom could auction one or more national licences. If the full 2x4MHz of spectrum is available, Ofcom could award two blocks of spectrum, as this may facilitate the emergence of competing band managers. However, if only 2x2MHz is available (owing to reservation of spectrum for public safety), then it will probably only be feasible to award one block. In this case, Ofcom would need to consider whether there may be insufficient constraint on the band manager from competition or users being able to access substitute spectrum. National blocks of frequency could be assigned by a simple sealed bid or ascending bid auction.

Our preferred way forward is Option 2, providing practical difficulties in implementing the band management model can be overcome. It is the simplest to implement, and should allow greatest flexibility for competition between different types of use both at the primary assignment stage and in the secondary market. However, the viability of this approach depends on there being demand from parties willing to take on the role of band managers; otherwise there may be inefficient delay in bringing spectrum to PMR/PAMR users relative to Option 1. Firm evidence of such demand is currently lacking. Nevertheless, there are reasonable grounds for believing that private interest in band management will increase once Ofcom has clarified the role of the band manager, in particular in relation to interference coordination and policing, and competition concerns.

Our preference for Option 2 requires that Ofcom can move quickly to develop a clear framework for band management. In the SFRIP, Ofcom envisages an award in 2005/06. If the process of developing a band management framework and 'marketing' the associated model (to both bidders and PMR end users) resulted in slippage in this timetable, then the costs of delay (in terms of denying access to PMR users) may be too great to justify this approach. It should be noted that proceeding with a transmitter-based licensing approach would not preclude the transfer of band management rights from Ofcom to a private party in the future, provided that licensees were made aware of the possibility that spectrum could be subject to future band management at the time of primary assignment. However, any uncertainty over whether and under what terms band

management might be introduced could limit initial demand for spectrum from individual users.

872-876 & 917-921 MHz

Key findings

Demand for this spectrum is likely to be very limited as:

- These frequencies are unsuitable for GSM, as the available frequencies could not be used by handsets tuned to use the core GSM band.
- 2 x 4MHz is insufficient for most wideband technologies that could be deployed to provide public mobile or broadband access, but would be enough to deploy CDMA2000. Additionally, the spectrum is likely to be subject to coordination requirements to control interference with the neighbouring GSM band, which may prevent this band being used to deploy wide-area (macro) cellular coverage. The resulting restrictions may undermine the viability of deploying a national CDMA2000 network in this band.
- These frequencies could be used for PMR/PAMR or for programme making and special events (PMSE), but it is not a preferred band for these uses, owing to lack of available equipment.

Given this apparent lack of demand, it is possible that the spectrum – if assigned in the near future by auction – might be purchased speculatively or by a GSM operator as a guard band.

Recommendations

As there is an apparent lack of market interest in this spectrum, there does not appear to be a rush to release it to the market. A key issue to clarify is whether there is any remaining interest in using the spectrum once the market is aware of the need for more onerous coordination obligations with the neighbouring GSM band. Ofcom may therefore consider holding back the band until more concrete evidence of actual demand can be identified.

If Ofcom does proceed with allocating this spectrum, we recommend awarding a single UK-wide licence. We found no evidence of any regional demand. Although we considered the possibility of allocating the spectrum on a licence exempt basis, we do not recommend this without specific evidence of demand. Allowing licence exempt use could effectively sterilise the spectrum for some future licensed use, including any link-up with the GSM-R band (if this eventually became available).

A single licence would be suitable for assignment by auction. A first price, sealed bid format would be simple to implement and should be more robust to low competition scenarios than other formats. If there were more than two bidders, an Anglo-Dutch hybrid auction (combined ascending bid-sealed bid format) could be used to increase efficiency. The auction could be prefaced by a 'demand evaluation' stage, in which potential users submit initial applications. Ofcom could use this stage to inform a decision whether

proposed uses of the spectrum were sufficiently valuable to justify assignment at this time.

2010-2025 MHz and 2290-2302 MHz

Key findings

These two bands could be used to provide a wide range of services, including mobile voice and data, fixed wireless broadband and vision carriers for programme makers. Many different mobile and fixed technologies could be deployed in either or both bands. TDD systems could use either band, while FDD systems could operate with a duplex pair across the two bands. Alternatively, users could pair either band with other frequencies, such as the 3G expansion band at 2500MHz.

Of the two bands, the 2010-2025 MHz band is perceived as having higher value, as it is one of the core 3G bands available across Europe. Our interviews revealed strong interest in acquiring this spectrum for mobile, FWA and PMSE. It is possible to construct strong business cases for mobile and PMSE use. The viability of FWA depends on the amount of spectrum that is available and certain cases are also reliant on optimistic market assumptions being made.

The 2290-2302 MHz band is perceived as less attractive for mobile and FWA, owing to UK-specific availability. There was no interest in this band from mobile network operators (MNOs). For FWA, this spectrum is either an inferior substitute for the 2010MHz band (for TDD technologies) or a complement when paired with the 2010MHz band (for FDD technologies). These considerations do not affect PMSE, which already has equipment suitable for the band.

Recommendations

In the 2010-2025 MHz band, we recommend allocating three nationwide blocks of 5MHz. These should be licensed on a technology and service neutral basis (assuming this is allowed under EC harmonisation measures).

In the 2290-2302 MHz band, we recommend allocating two blocks of 5MHz using 2290-2300 MHz. These should be licensed on a technology and service neutral basis. The remaining 2MHz of spectrum could be held back from the market to be assigned with the adjacent 2302-2310 MHz band, when this has been cleared.

We recommend holding a combined auction for all five blocks of spectrum across the two bands (subject to early resolution of legal issues concerning EU harmonisation in the 2010-2025 MHz band). The format of this auction would be designed to help bidders mitigate aggregation and substitution risks across the two bands, thus facilitating an efficient outcome. Our proposed format is a sealed bid combinatorial auction. Bidders would submit a menu of alternative bids which reflect their relative preferences between different combinations of bids. Licences would be allocated to the combination of bids and bidders that maximised value. This would be quick

to implement and robust to the possibility of weak competition for the 2290-2300 MHz band.

The combined auction should be held as soon as possible, given evidence of significant demand, especially for the 2010-2025 MHz spectrum. Selling the spectrum quickly would maximise prospects for successful new entry and innovation in wireless broadband provision. Although there are demand linkages with the 3G expansion band, delaying assignment until this spectrum is ready for release appears undesirable as this would be damaging to the business cases of potential entrants and delay possibly significant consumer benefits.

1 Introduction

This report has been prepared by DotEcon Limited (DotEcon), Analysys Consulting Limited (Analysys) and Mason Communications Limited (Mason) for Ofcom as a summary of our study on allocation and assignment options for available spectrum in four bands. It provides an assessment of the potential uses of the spectrum, the relative value of these uses, and the likely level and nature of demand. In light of this market assessment and Ofcom's policy guidelines, we develop recommendations for packaging of spectrum usage rights and suitable assignment mechanisms.

1.1 Background to the study

Ofcom commissioned this study to assess the options for allocating spectrum that is available in four bands:

- 410-415/420-425 MHz – this spectrum was previously used on a paired basis by Dolphin for operating a national public access mobile radio (PAMR) network using TETRA technology.
- 872-876/917-921 MHz – this spectrum was previously allocated to Dolphin on a paired basis for the deployment of next generation technology (TETRA2).
- 2010-2025 MHz – this spectrum is currently allocated to unlicensed usage by systems compliant with IMT-2000 TDD specifications.
- 2290-2302 MHz – this spectrum was historically used for fixed links.

The objectives of the study were to:

- identify and assess the business opportunities that the bands offer, including an assessment of the level of interest in bidding for spectrum, the valuations that bidders may put on the licences, the characteristics of the companies that may bid, and any related competition concerns; and
- provide guidance to Ofcom on the design of the award process. This includes recommendations on the suitability of awarding licences by auction, appropriate auction formats, timing of awards and key auction rules.

1.2 The Spectrum Framework Review

During the period when this study was being prepared, Ofcom released two consultation documents on spectrum policy which are directly relevant:

- *The Spectrum Framework Review* (SFR) – a consultation on Ofcom's views as to how radio spectrum should be managed.
- *The Spectrum Framework Review: Implementation Plan* (SFRIP) – a consultation on the release of spectrum in 2005-08, which includes specific comments on the bands being analysed in this study.

Introduction

The SFR gives general guidance on the application of trading and liberalisation to spectrum, and on the use of auctions for spectrum assignment. These policy guidelines, which we discuss below, provide a framework for our analysis of allocation and assignment options in the selected bands. However, this study was completed in January 2005, whereas the SFR consultation closes in February 2005. Therefore, this report does not take into account any responses to the consultations or conclusions that Ofcom might draw from these.

Ofcom's general approach to spectrum management is to allow the market to determine allocation (uses) and assignment (users), whenever possible. According to the Ofcom Spectrum Vision, as described in the SFR, "*spectrum should be free of technology and usage constraints as far as possible*". It should also be "*simple and transparent for licence holders to change the ownership and use of spectrum*".

To realise these goals, Ofcom intends to introduce secondary trading and liberalisation of use progressively across selected spectrum bands over the next five years. By 2010, it anticipates that over 70% of spectrum below 3GHz will be subject to trading and liberalisation. These policies will apply both to existing spectrum allocations and to primary assignments of spectrum.

Ofcom is already following "*a policy of using auctions as the most appropriate means to distribute spectrum that is not currently assigned or has been 'returned'.*" Auction design should reflect the "*best information available on the most likely use"* but should be sufficiently flexible *"such that if it subsequently transpires that a different use is optimal then the market can move to this use.*"

In certain cases, it may not be possible to use auctions, or to introduce trading and liberalisation. Possible constraints on the use of market mechanisms include difficulties with the market-based management of interference, the need to conform to binding international agreements, risk of market failure (e.g. owing to high transaction costs) and specific public policy goals. In such cases, some intervention may be required to facilitate efficient allocation and assignment. It is Ofcom's intention that such policy intervention should only be used where it can be justified.

Our recommendations take account of Ofcom's preference for using auctions to assign spectrum, and that spectrum usage rights should be tradable and free of technology and usage restrictions, whenever possible. For example, with respect to the packaging of spectrum usage rights, we consider the extent to which decisions on their configuration (e.g. size of spectrum blocks, national/regional division) need to be made by Ofcom or can be determined in the secondary market.

The SFRIP includes Ofcom's initial assessment of options for allocation and assignment of spectrum in the four bands analysed in this study. It also outlines proposals for the release of other spectrum that may be substitutes or complements to these bands. Although the document includes specific proposals for the four bands, it makes clear that these are subject to further

analysis, undertaken with the assistance of external consultants. Our understanding is that this study will form a key part of that further analysis.

1.3 Structure of this report

This report is divided into an introduction and seven further sections:

- Section 2 describes our approach for the two phases of the study: market assessment and consideration of assignment options.
- Sections 3-6 outline our main findings and key recommendations on a band-by-band basis. Each section consists of nine subsections:
  - The first five subsections relate to the market assessment phase of the study. They describe the available spectrum and constraints on its use; identify potential uses; assess potential demand for these uses, in light of interviews with relevant parties; explore the viability of potential uses; and comment on any implications for competition in related markets.
  - The remaining four subsections relate to the assignment options phase of the study. In these parts, we provide recommendations on packaging of spectrum usage rights; discuss the desirability of using auctions to assign the rights; explore specific auction or other assignment options; and discuss the appropriate timing of an award process.
- Section 7 provides a summary of our main findings and recommendations.
- Section 8 describes the next steps which Ofcom could take to facilitate the award of usage rights.

In addition to this report, we also prepared a number of confidential annexes for Ofcom. These consider the detailed responses to interviews with stakeholders (on an anonymous basis). They also provide financial models of potential uses of the various bands and an assessment of the viability of certain business models. These annexes are not included in this report in order to protect both the confidentiality of interviewees and avoid disclosure of data that might potentially be market sensitive.

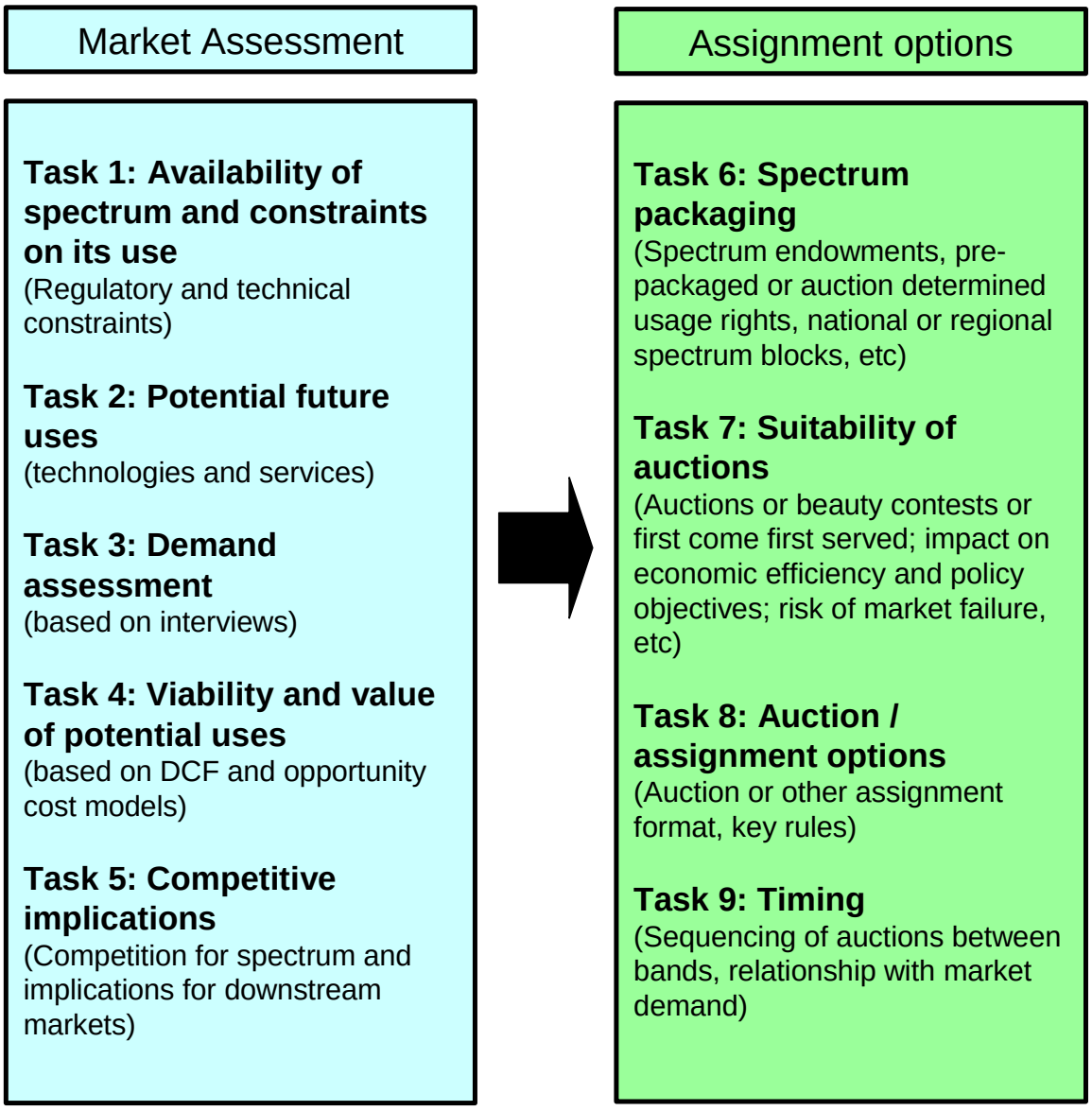
Although we discuss each of the four bands in separate sections, we are mindful of the fact that many of the potential uses of these bands are related. Wherever there are linkages between the bands that could affect allocation or assignment decisions, these are addressed in the appropriate sections under each bands, and highlighted in our summary of findings and recommendations. There are also interrelationships with bands which fall outside the scope of this study (e.g. the 3G expansion band at 2500 MHz), but which we nevertheless consider.

2 Our approach

The study consisted of two stages: market assessment and consideration of assignment options. These two stages are closely related, in that the results of the market assessment, together with Ofcom's policy objectives, are the critical inputs into the selection of assignment options, including auction design.

In Sections 2.1 and 2.2, we briefly describe the approach taken to complete the key tasks under these stages. Figure 1 provides a summary of our overall approach.

Figure 1: Overview of our approach



2.1 Market assessment

The market assessment stage of the study consisted of five tasks. Although separate market assessment exercises were conducted for each of the bands, we also considered the potential linkages between the bands arising from users being able to use them as substitutes or complements.

2.1.1 Task 1: Availability of spectrum and constraints on its use

Our first task was to clarify the availability of spectrum in each of the bands, and any existing technical and regulatory constraints on its use.

Possible constraints relevant to these bands include:

- The existence of international agreements which create mandatory or voluntary constraints on the use of spectrum in specific bands, for example EC Directives, ITU Radio Regulations and CEPT Recommendations.
- Restrictions to the timetable for introducing trading and liberalisation; for example, Ofcom has stated that it does not intend to liberalise use of spectrum for 3G services prior to 2007.
- The risk of harmful interference to existing or neighbouring users of the bands. These may impose limitations on the type and/or geographic location of use. For example, the 410-415 and 420-425 MHz bands are subject to geographic and power restrictions in order to prevent interference with RAF Fylingdales.
- Other specific government policy goals, for example possible reservation of spectrum for public safety uses.

2.1.2 Task 2: Potential future uses

The next step was to identify the principal technologies and services that could be used in each band, given the technical and regulatory constraints identified under Task 1. We then identified the types of services that could be provided using these technologies. Our initial list of technologies and services was drawn up using the project team's and Ofcom's own knowledge of wireless technologies, plus additional desk research. Subsequently, it was extended to incorporate any further technologies and services identified through interviews with stakeholder groups (see Task 3 below).

In considering future uses, we have taken into account Ofcom's preference that the bands should be allocated (if possible) on a technology and service neutral basis. One possible exception to this is that Ofcom's spectrum trading consultation document[1] does not anticipate allowing liberalised

[1] Ofcom, Nov 2003, *Spectrum Trading Consultation*, paragraphs 8.2.13 & 9.4.10.

spectrum bands to be used for the provision of 3G services until the end of the transition to full liberalisation and trading, scheduled for 2007. Ofcom is currently in the process of reviewing this issue, including the definition of "3G services".

For the purposes of this study we have assumed that the restriction is maintained that bands not presently designated for 3G may not change their use to offer 3G services until 2007. However, our ultimate conclusions are sensitive neither to how this condition might be interpreted nor to whether it might be varied in some way. Indeed, even if one were to take an extremely wide definition of 3G services (say to include services in the same economic market as those offered by 3G licensees, rather than a technology based definition), this is unlikely to form a significant constraint on spectrum assignment in the near term. Any potential operator still needs to obtain radio spectrum and build a network before offering its service, which would in an case be unlikely to reach market much before 2007 even without this restriction. Therefore, it is unlikely that the restriction will make any significant difference to the demand for and valuation of spectrum bands being analysed.

2.1.3 Task 3: Demand assessment

The objective of this task was to understand the level of interest from organisations in using the spectrum to provide specific types of services, and the potential availability of equipment and funding. From November 2004 to January 2005, we carried out interviews with 41 organisations, including commercial spectrum users (e.g. mobile network operators, existing or potential wireless broadband providers), public users (e.g. London buses), equipment manufacturers, existing spectrum management organisations and financial institutions.

Table 1 provides a list of the organisations that we interviewed. Interest in the spectrum varied considerably across the different types of organisation and by band – as discussed in Sections 3 to 6 below.

Table 1: Companies and institutions interviewed

Potential / existing operators	
Existing mobile operators	3, O_2, Orange, T-Mobile, Vodafone
ISPs	AOL, Pipex
Fixed operators	BT, C&W
Wireless broadband operators	UK Broadband
Potential future mobile / PAMR operator	Inquam
Manufacturers	
Mobile / wireless broadband manufacturers	Alvarion, Flarion, IPWireless
PMR / PAMR equipment manufacturers	EADS / Cogent, Marconi Selenia, Motorola, Nokia, Simoco
Mobile equipment manufacturers	Ericsson, Lucent, Motorola, Nokia, Siemens
PMR / PAMR stakeholders	
Dealers / Users	2CL, Air Radio, Fleetcomm, London Bus/TfL, Procom, Relcom
Band managers	CSS Spectrum Management, JFMG, JRC
Industry group	FCS
Public safety organisations	
Operators	Airwave
Users	Ambulance service, PITO (police)
Financial institutions	
Banks	ABN Amro, Bank of Scotland
Private equity	Carlyle Group, Doughty Hanson

2.1.4 Task 4: Viability and value of potential uses

To assess the viability of the uses of spectrum identified in Tasks 2 and 3, we adopted a similar approach to the one that might be used by bidders to value the spectrum. Our specific methodology varied by type of use considered but typically involved the construction of a high-level business model projecting revenues, capital expenditure and operating costs associated with the use of the spectrum. From this, we were able to derive

a cash flow for the opportunity being modelled and so calculate the net present value (NPV) of the free cash flow arising from the business.

2.1.5 Task 5: Competitive implications

There are two broad sets of issues that need to be considered in relation to competition:

- the likely extent of competition for spectrum in a certain band; and
- the implication of the allocation and assignment process on competition in the provision of services to end-customers.

The extent of competition for a certain band depends on expected demand and the availability of other bands that may offer substitute or complementary spectrum. Spectrum packaging may affect the number of users that can be sustained (though the secondary market may reconfigure licences), and so may affect the extent of competition for a particular licence.

The extent of competition for spectrum is an important determinant of the most appropriate form of assignment process. In particular, if there is a significant risk that competition may be weak (either because there are few bidders or they are very asymmetric in strength) it may be prudent to use forms of auctions (such as sealed bids) that are less adversely affected.

We must also consider effects on competition in the provision of services to end customers. Competition for spectrum is not sufficient to guarantee competition in the provision of services. For example, if access to a particular spectrum band were essential for the provision of a particular service, there could be vigorous competition to secure the right to be a monopoly provider of services, dissipating any excess profits that might be earned by the provider.

In general, spectrum liberalisation is greatly reducing the linkage between particular spectrum bands and particular services. This, in turn, greatly reduces the scope for competition problems in end markets, as it may be infeasible to monopolise a services market simply by acquiring spectrum; there may be too many alternatives for providers of similar services to make such a strategy successful.

Nevertheless, we must still check that a particular band is not subject to potential monopolisation because there is little alternative spectrum that could provide substitutable services to end users. Clearly this cannot be the case in mobile services or wireless broadband services, as there is already competition in the former and the later competes with wireline services. However, there is greater need for scrutiny in the case of private mobile radio (PMR) and PAMR services, as there is a single TETRA network and spectrum for digital PMR systems is currently relatively scarce.

This said, even if there are possible adverse effects on competition in provision of services to end-users, competition law is available to address such problems. Therefore, we limit attention to competition problems that

might be created or exacerbated by how spectrum is assigned and where competition law is an insufficient remedy by itself.

2.2 Assignment options

Our findings from the market assessment stage of the study formed the key inputs into our analysis of assignment options for each of the four bands. This stage of the project consisted of four tasks, as described below. As with the market assessment, we have presented our findings separately for each band; however, our approach also considered the impact of linkages in demand between the bands.

2.2.1 Task 6: Spectrum packaging

Under this task, we developed recommendations on the packaging of spectrum lots for assignment. The way that spectrum lots are defined can affect the uses that are possible. Rights to transmit or receive signals over spectrum can be defined in relation to a number of parameters:

- *Spectrum endowment* – the frequency bandwidth to which access is granted. Different technologies and services require different bandwidths. Some services, for example some new mobile broadband technologies require single contiguous blocks, whereas 2G and 3G mobile systems require paired spectrum in separate frequency blocks for send and receive paths. Spectrum endowment also affects the number of usage rights available, which might be fixed or vary according to the number of lots that each user acquires. This may have implications for the scale of entry in downstream service markets.
- *Geographical area* (e.g. an entire country, a region or a defined area around a base station).
- *Time of access* (e.g. access to spectrum throughout the entire day, or at a specific time of day).
- *Duration* (e.g. unlimited or defined-length usage rights). In general, Ofcom is in favour of granting usage rights with a continuous rolling term.[2]
- *Protection from interference* – the right to receive signals without harmful interference from other spectrum users, and the obligations not to cause such interference.
- *Other licence conditions* – these could include restrictions on the type of technology or service, or public service obligations tied to licences. Such imposition should generally be avoided unless required to prevent market failure or to promote public policy goals.

[2] Ofcom/RA, Spectrum Trading, Consultation Document, November 2003, p.33-34.

In general, spectrum packaging should be consistent with as many uses as possible, based on an assessment of anticipated market needs and the available equipment. It should not unduly constrain future trading or change of use in the secondary market. A spectrum packaging framework that is consistent with various possible developments in technology should result in a more rapid diffusion of new services, with consumers gaining from higher quality and lower prices.

2.2.2 Task 7: Suitability of auctions

There are a variety of assignment mechanisms that Ofcom could use for distributing the spectrum in the four bands. These include:

- first come first served (FCFS);
- direct awards;
- comparative selection (also known as 'beauty contests'); and
- auctions.

FCFS is the standard approach where there is no excess demand for spectrum, although administrative incentive pricing (AIP) may be required alongside. In particular, FCFS without any charges might encourage speculative requests for spectrum and so lead to excess demand. Direct awards are made only when there are clear public policy reasons for discriminating in favour of a particular user, for example assignment of spectrum to emergency services. Where there are competing demands for spectrum, an auction or administrative decision based on comparative selection will normally be required.

As part of our project brief, Ofcom indicated a general preference for assigning the available spectrum using auctions, but asked for recommendations on their suitability. This is consistent with Ofcom's policy objective of allowing the market to determine assignment unless there are strong public policy objectives or expectations of market failures that suggest an alternative approach is needed. In the following paragraphs, we briefly outline the main factors which have guided our assessment of the suitability of auctions for each of the bands.

The main arguments in favour of using auctions are as follows:

- *Efficiency.* A well-designed auction is economically efficient, ensuring that licences are awarded to those bidders with the strongest business cases – which usually corresponds to their ability to generate most value for society providing that competition in the provision of services is effective. Where there are competing uses as well as users, it may be possible to design the auction to allow them all to participate, with the result that the auction determines allocation as well as assignment.

  By contrast, with administrative approaches, it is difficult for regulators to define objective criteria to distinguish between

competing bidders and different uses. They may have poor information on which to base the selection of winners.

In an auction, bidders have strong incentives to make bids that reflect the value to them of the licence, as they face paying what they bid. This is not necessarily true with beauty contests, where applicants may have an incentive to exaggerate their business cases in order to increase their chances of winning a licence. Indeed, as governments are usually very reluctant to revoke licences, some applicants may calculate that there is little downside risk to making promises that they may not be able to keep.

- *Public interest.* Auctions enable the public to realise the full scarcity value of licences through transfers from private operators. Raising the "market value" of licences is often cited as a key objective in using auctions, albeit one that is secondary to achieving an efficient outcome. Wolfstetter (2001) argues that, provided an auction outcome is efficient, revenues are akin to a "distortion-free tax", and that this is therefore a particularly advantageous way for governments to raise revenues in order to finance their expenditure.[3]
- *Speed.* Using auctions can be significantly faster and less-resource intensive than comparative selection in assigning licences. Even quite complex auctions, such as the simultaneous sale of many different spectrum licences, can be completed in just a few days using specialised auction software and bidding over the Internet or private networks. The FCC has found that auctions can save months or even years of regulatory or other delay.[4]
- *Transparency.* Auctions can be designed to be completely transparent, reducing the risk of accusations of bias and legal challenge from unsuccessful applicants. By contrast, beauty contests are acutely vulnerable to criticism. Many governments chose not to publish the criteria on which comparative selections are made. This risks creating the appearance that the government is making decisions that are biased towards or against particular industry players. Even where both criteria and scoring details are published, losing applicants may seek to challenge aspects of the process. This could result in legal delays to assignment, with detrimental effects for industry development and competition.[5]

---

[3] Wolfstetter, May 2001, T*he Swiss UMTS Spectrum Auction Flop: Bad Luck or Bad Design?*, Institut f. Wirtschaftstheorie I, Humboldt Universität zu Berlin, p.6.

[4] US Federal Communications Commission, 1999, *Connecting the Globe*.

[5] For example, Ireland's award of a third GSM licence was delayed by around two years owing to legal challenge from a failed bidder over the selection criteria. As a result, the new operator (Meteor) launched into a market with high penetration and slowing growth, instead of entering at the peak of the market's expansion.

- *Bidder self-interest.* Although the cost of acquiring a licence through an auction can be considerable (if there are several strong bidders), potential licensees may prefer auctions to comparative selection because of their transparency and the certainty of being able to acquire a licence if they have the best business proposition.

Despite these advantages, there are circumstances where there is spectrum scarcity when auctions are inappropriate or where significant adjustments to standard auction approaches may be required. These include:

- *High transaction costs*. Where there are many small users of spectrum, for example as with PMR, there may be high search or participation costs in involving them in an auction. If many small users are unable to coordinate their demands, they may lose out to other users with more aggregated demands, despite collectively placing higher value on using the spectrum.[6] Conversely, breaking spectrum down into a large number of lots might disfavour bidders needing to aggregate together many lots. Either way, spectrum might not be awarded to those placing the greatest value on it. It may be possible to overcome this problem through the allocation of spectrum to band managers, who act as demand aggregators.
- *Fragmented demand*. A related problem is that of fragmented geographic demand for spectrum, which potentially affects both PMR and PAMR. In this case, it may be difficult to divide spectrum into predetermined and exclusive lots, as there would be an infeasibly large number of such lots.[7]
- *Competition concerns*. As discussed under Task 5, control of spectrum may have implications for competition in the provision of services to end-customers. Such problems should normally be resolved through application of competition law at the sectoral level. However, auction design can be amended to take such factors into account, for example through bidding restrictions on incumbent bidders and the use of auction formats that are more robust to asymmetries in the strength of bidders.

  Auctions can also be vulnerable to strategic manipulation by bidders seeking to depress prices (e.g. as in the case of the Netherlands and Swiss 3G auctions). However, the risk of such problems can be minimised through good auction design.
- *Social externalities*. The efficiency of auction outcomes is predicated on the assumption that private value of spectrum to a particular user is

[6] This issue has been raised as an important rationale for combinatorial auctions, which may be more efficient in such circumstances.

[7] An example is PMR users wanting rights to use spectrum over limited geographical areas that are difficult to forecast.

equal to the public value that user creates. This may not be the case if there are externalities, as the willingness to pay of users does not reflect the social value of allocating the spectrum to them. However, there may be simple solutions to the problem of socially provided services, such as providing subsidies to the public bodies charged with providing these services in order to acquire spectrum or making a direct grant of some spectrum. Therefore, such problems are not necessarily incompatible with using market mechanisms.

- *Other public policy concerns*. Assignment by auction may be perceived as conflicting with broader public policy goals, such as promoting new entry, rules on broadcasting plurality or use of spectrum for public safety services. However, Ofcom's policy is that such issues should be resolved, whenever possible, at the sectoral level, rather than through intervention in spectrum distribution.

2.2.3 Task 8: Auction / assignment options

Having established the suitability of using auctions to allocate and assign spectrum in each of the bands, we then identified candidate auction formats (or other assignment procedures where appropriate). We then set out the relative advantages and disadvantages of each format, and – on this basis – have made specific recommendations for their use. For our preferred auction formats, we have also made some initial comments about associated participation, activity and payment rules required to ensure that the auction design is effective. However, as agreed with Ofcom, we have not provided detailed advice on rules, as this will be required only once Ofcom has made a decision on either a specific format (or limited choice of candidate formats for further analysis).

In our assessment of assignment options, we have considered the full range of possible auction formats, including[8]:

1. *Single round, sealed bid auctions*. Bidders submit a single bid (or set of bids) in a single round. The bid results are only announced once the round is closed. Licences are awarded to the highest bidders.

   This type of auction is simple, quick and cheap to administer, and can be used for assigning either single or multiple licences. However, relative to ascending bid auctions, there is increased risk of inefficiency in assignment (licences not going to the strongest bidder) and winners' curse (winning bidders overpaying). With multiple spectrum lots, bidders are also exposed to substitution and aggregation risks, depending on the structure of demand. For these reasons, academic

[8] A more detailed assessment of these auction formats can be found in: DotEcon and A-Focus, April 2004, *The Use of Auctions in Spectrum Assignment, a report for PTS*, available at www.dotecon.com/publications.

literature on spectrum auctions has traditionally favoured ascending bid processes over single round contests. However, sealed bids are potentially more robust to collusion between bidders and can encourage entrants to compete against established incumbents.[9]

2. *Single unit, ascending-bid auctions*. The auction takes place over multiple rounds. In each round, bidders place increasing bids on the single spectrum lot. The auction closes when there is only one bidder left that is willing to pay the asking price.

   This is also a very simple auction to administer. It should normally result in a more efficient outcome than a sealed bid auction, provided there is no one strong incumbent bidder.

3. *Simultaneous multiple-round auctions (SMRAs)*. This is an ascending bid format designed to cope with multiple lots being sold simultaneously. In each round, bidders place increasing bids on licences. The auction closes when no new bids are forthcoming. Each licence is assigned to the highest bidder.

   SMRAs have been widely used for assigning spectrum licences, and there has been huge variety in specific design, especially in relation to activity rules, transparency and restrictions on bidder participation. The 'standard' SMRA format, which was used, for example, for assigning UK national 3G and regional BFWA spectrum, features a number of distinct licences. The price of a licence only rises when it receives a new bid. Thus, over the course of the auction, the prices of different licences will vary and bidders can switch between them on the basis of their relative price.

   Where there are multiple, related spectrum lots, an SMRA format will normally deliver the most efficient spectrum auction outcome, unless there are competition/entry concerns. Bidders benefit from being able to observe the behaviour of their competitors and alter their demand in response to changes in the relative prices of licences. This mitigates both winners' curse and substitution risks, and reduces aggregation risks, relative to a sealed bid.

4. S*imultaneous clock auctions.* This is a distinct variant of the SMRA, which is used for selling multiple, identical lots. In this format, there is a common price for all lots that increases in each round until aggregate bidder demand falls to a level where it matches supply. Unlike some standard SMRA formats, bidders always pay the same price for identical licences.

[9] Klemperer, 2002, *What really matters in auction design*, Journal of Economic Perspectives, 16(1), 169-189.

This format may be appropriate if there are bidders with different demands for spectrum within a band and it is possible to break the band up into multiple lots of equal spectrum endowment. A prerequisite is that bidders do not have significantly different valuations on different frequencies within the band. After the auction, a subsequent process is required to allocate specific frequencies to winning bidders.

5. *Combinatorial auctions.* Combinatorial bidding can be used in either a sealed bid or ascending bid context, where bidders have synergies between multiple spectrum lots.[10] Unlike a standard auction, bidders can submit multiple bids, one for each combination of licences that they are eligible to acquire. Put differently, bidders can submit bids for both individual licences and for combinations of licences, and vary the amounts they bid to reflect any synergies. The highest bidders are determined by calculating the combination of bids across bidders and licences that generates the highest revenue.

   The rationale for introducing combinatorial bidding is rather different for sealed bids and for open auctions. In the case of a sealed bid, allowing bidders to make a menu of mutually exclusive bids for combinations of lots allows them to express preferences for substituting and combining lots that cannot be expressed in a regular sealed bid process due to its one-shot nature. This allows for more efficient outcomes, in particular avoiding lots becoming inefficiently fragmented across different winners.

   Adding combinatorial bidding to an open auction can improve efficiency in the specific circumstance when:

   "(a) *there are strong complementarities [synergies] among licences for some bidders, and (b) the pattern of those complementarities varies for different bidders"*. [11]

   In this situation, combinatorial bidding can remove aggregation risks for bidders, allowing them to bid up to their full value for licences, without risk of being stranded with unwanted subsets of their total demand. This creates a more level playing field between bidders trying to aggregate lots and not trying to aggregate (or aggregate to a lesser extent). This tends to increase the likelihood of achieving efficient outcomes. Reduced aggregation risks and increased competition between bidders with different patterns of complementarities across lots will also tend to increase revenues.

---

[10] For a good overview of combinatorial auctions, especially in relation to ascending bidding, see Ausubel and Milgrom, 2002, *Ascending Auctions with Package Bidding*, Frontiers of Theoretical Economics: Vol. 1: No. 1, Article 1.

[11] Public Notice DA 00-1486, US Federal Communications Commission, July 3, 2000.

However, there are some potential problems with using combinatorial bidding:

- *Complexity.* Combinatorial bidding is simple with very small numbers of lots, as the number of combinations is limited. However, with large numbers of lots, combinatorial auctions may be complex as the task of determining winners (both at the end of the auction and round-by-round for open auctions) becomes computationally demanding.[12] This may make such auctions difficult for both the auctioneer and bidders to understand, especially in a multi-round context.
- *Transparency*. The outcome, although fair, may not be very transparent to bidders and observers, especially if it is necessary to use a computer algorithm to identify the successful bids.
- *The 'threshold' problem.* In certain instances, it may be possible for bidders to use combinatorial bids to leverage their advantage in one region to win licences in another, even though their demand is in fact unrelated. If relevant, this could disadvantage bidders pursuing smaller numbers of regions.

The use of combinatorial auctions has recently been championed by the US FCC. However, it has repeatedly delayed plans to use an ascending combinatorial (package bidding) format for the auction of spectrum in the Upper 700MHz band.[13] While this delay reflects concern about low demand for licences, it is also apparent that the FCC has struggled to develop practical rules.

To date, the only examples of spectrum auctions using combinatorial bidding are the 2001 Norwegian mobile spectrum auction and the 2002 Nigerian FWA auction. Of these, the Norwegian auction was a particularly simple design and did not attract much demand. A better test of the format was the Nigerian auction, where there was significant excess demand for licences. In this auction, the designers used a sealed bid process and limited the numbers of licences in each region to four or five, in order to reduce complexity for bidders.[14] The format was effective and easy to implement.

6. *Hybrid auctions*. It is possible to combine the features of more than one auction format, with the objective of realising the advantages of

[12] The computational burden of determining winners increases exponentially with the number of lots.

[13] There is currently no scheduled start date. See http://wireless.fcc.gov/auctions/31/ for details of the auction design.

[14] Koboldt, Maldoom and Marsden, , 2003, *The first Combinatorial Spectrum Auction - Lessons from the Nigerian auction of fixed wireless access licences*, DotEcon DP No. 03/01, available at www.dotecon.com/publications.

more than one format and/or eliminating the disadvantages associated with using one format by itself. For example, in the original plans for the UK 3G auction, the design team proposed an 'Anglo-Dutch' format to sell four licences.[15] Bidders would have participated in an SMRA-type auction until there were just five bidders left (one more than the number of licences). At this point, the auction would have been concluded using a sealed bid. This format is designed to combine the efficiency (anti-winner's curse) advantages of an ascending bid and the entry attraction benefits of a sealed bid. It was specifically proposed to address the situation where there is the same number of strong incumbents as there are licences available.

In assessing the relative advantages and disadvantages of these formats for each band, we took into account a range of factors, including:

- the number of lots;
- the anticipated level of demand;
- the scope for substitution and extent of complementarities between lots, both within and across bands;
- the likelihood that the auction format will deliver an efficient outcome (specifically whether there might be common value uncertainty that could be reduced by the extra information provided by an open auction format);
- the incentives created by the auction format for bidder participation (especially whether the auction format might magnify asymmetries between entrants versus incumbent operators);
- the complexity of the auction format and the cost of implementation; and
- possible economies of scale in implementation by deploying the same or similar auction formats for different bands, without sacrificing efficiency.

Note that there are many variants of the auction formats above, depending on the specific rules selected. Getting the detailed auction rules right is just as important as picking the appropriate format. These rules need not necessarily be long or particularly complicated but their impact on bidder behaviour must be carefully thought through. At this stage, we have only commented on detailed auction rules to the extent that they are fundamental to the selection of one particular auction (or other assignment)

[15] Binmore and Klemperer (2002), *The Biggest Auction Ever: The sale of the British 3G Telecom Licences*, The Economic Journal, 112, C74-C96 It is unclear why these authors have called this format 'Anglo-Dutch'. Normally, the term 'Dutch auction' is used to refer to a descending bid format, but in this case it refers to the sealed bid component of the auction.

format over another. Therefore, the task of turning the recommended auction formats into specific sets of detailed auction rules remains.

2.2.4 Task 9: Timing of award

Our final task was to provide recommendations for the timing of the auctions. For each of the bands, we have provided advice on:

- *Downside of delay*. There may be significant costs of delay in assignment of spectrum, especially in regard to new services such as wireless broadband and digital PMR. For example, delays may undermine the business the case for new entry of a wireless technology that will compete with an existing fixed technology in a growing market. They may also set back the timeframe for the roll-out of a new service, thereby depriving consumers of benefits from their use.[16]
- *Sequencing of auctions*. Whether the order in which the various spectrum bands are auctioned will have any efficiency or revenue implications. Sequencing auctions appropriately is important if demand for spectrum in one band is at least in part contingent on particular bidders acquiring spectrum in another band. If the relationship is two-way, then it is usually best to auction both bands simultaneously; if it is one-way only, then it should be practical to auction spectrum separately without unduly reducing efficiency.
- *Relationship with the market*. Whether there are any market-related factors that may influence the timing of the auction. For example, in the case of the UK 3G auction, timing in relation to market interest in 3G and other European auctions was an important factor behind the successful outcome.

Spectrum auctions, like any assignment process, may require significant preparation, both for the auctioneer and for bidders. We have therefore also provided some initial comments on time and resources required to implement our recommended options.

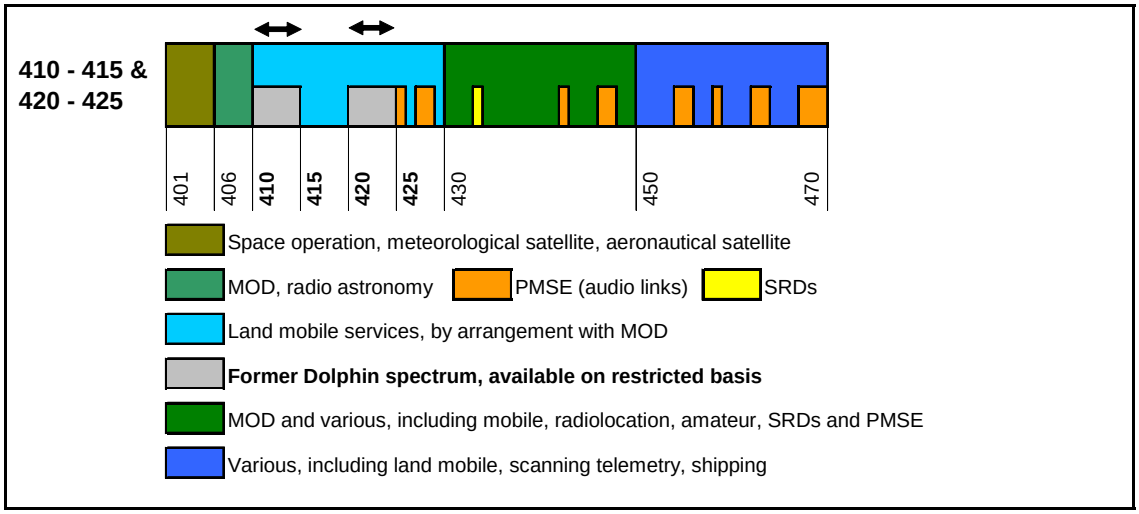
[16] For example, in 1997, Hausman, (1997, *Valuing the effect of regulation on new services in telecommunications*, Brookings Papers on Economic Activity, Microeconomics) estimated that the total cumulative cost of delays by the Federal Communications Commission (FCC) in making spectrum available for use by US mobile network operators was around USD100 billion. This represents lost consumer surplus.

3 The 410-415 MHz & 420-425 MHz band

The available spectrum consists of 2 x 4MHz with 10MHz duplex spacing, which is currently fragmented across the 410-415 MHz and 420-425 MHz bands. This spectrum is located within the wider 410-430 MHz band, which is currently allocated to land mobile services (and some PMSE[17] use) by arrangement with the MoD. The location of the spectrum and neighbouring uses is illustrated in Figure 2.

The available spectrum was previously assigned to Inquam Telecom Holdings Ltd (formally Dolphin Telecommunications Ltd) in the mid 1990s to provide public services using TETRA technology. Following the entrance into administration of the parent company, the licences were revoked in July 2004 and the bands are currently un-used for civil systems.

Figure 2: The 410-430 MHz band and adjacent spectrum



3.1 Available spectrum and constraints on its use

The main constraint on use of this spectrum is the need to coordinate civil and military use. The configuration of available spectrum and the aggregate number, location and power output of transmitters are subject to restrictions imposed by the MoD. As we discuss below, the role of the military in this band – in particular the coordination requirements created by the MoD radar

[17] Programme making and special events: a collective term used to describe the provision of news, film, television, stage, concert and sports programming through the use of radio spectrum.

installation at Fylingdales – is foremost amongst a number of factors causing uncertainty for potential users.

Here, we highlight six factors which may impose constraints on the use of the band and/or are a source of uncertainty for users. Many of these constraints and uncertainties are not fixed and could be eased through action by Ofcom.

3.1.1 Availability and fragmentation of spectrum

The available spectrum was significantly fragmented when it was originally licensed to Dolphin, causing difficulties in optimising the frequency re-use employed in that network. Dolphin used 160 25kHz duplex channels; of this, it is understood that only 2 x 100kHz (four channels) were contiguous and available across the United Kingdom, with the remaining channels dispersed across the band. However, this configuration may be revised as we understand from Ofcom that the MoD are prepared to reconfigure the channels to offer larger contiguous blocks. Within the reconfigured blocks there will be military use at various sites, with restrictions on civil use in their vicinity that may be lifted through negotiation between the eventual licence holders, Ofcom and the MoD.

Two possible outcomes of these discussions are as follows:

a) two contiguous 4MHz blocks with 10MHz duplex spacing (e.g. 410-414 MHz paired with 420-424 MHz); or

b) a single contiguous 8MHz block in the range 410-420MHz.

The configuration of the spectrum affects potential uses and business plans. If the current configuration is maintained, then use of the band will be limited to narrowband technologies fitting the 10 MHz duplex arrangements, e.g. TETRA or other digital PMR/PAMR technologies. Option (a) above would also support TETRA and potentially other uses too, whereas option (b) would not be compatible with current TETRA duplex arrangements but would be more appropriate for some wideband technologies.

Subject to the re-configuration, there is likely to be a portion of spectrum available nationwide. However, MoD use of the band means that some geographic restrictions will remain, in particular owing to co-ordination necessary to protect the Fylingdales radar (see below).

3.1.2 Management of the spectrum

Although Ofcom is responsible for civil assignment of this spectrum, the band is managed by the MoD and civil use is by their agreement. Our discussions with potential users of the band indicate that this military use is a source of uncertainty, as there is concern that the MoD may not be very flexible in exercising its management role and over the usability of the spectrum. Greater clarity over the MoD's position and any impact this has on the rights of civil users to use and trade spectrum could encourage interest in the spectrum.

In the SFRIP, Ofcom raised the possibility that the spectrum could be awarded to an organisation acting as a band manager:

> *"The band manager would itself be a licensee of Ofcom but would have the ability to give third parties access to rights on a commercial basis. The role of the band manager is in some ways similar to the role Ofcom currently performs in assigning spectrum to individual uses but the band manager would be free to develop innovative ways of assigning spectrum in the light of its perception of market demands."*[18]

In principle, a private band manager could also take on at least some of Ofcom's responsibilities for coordinating civil use with the MoD. However, we understand from Ofcom that it is likely that the MoD will prefer to continue using Ofcom as an intermediary through which all discussions with civil users take place. This arrangement may be best for everyone, as our interviewees were wary of having to deal directly with the MoD, and expressed concern about how quickly and flexibly the MoD would respond to civil requests for changes to current uses.

Our understanding is that the agreement between Ofcom and the MoD (as currently constituted) would require a band manager to notify the addition of a user or a change of transmitter site to Ofcom to ensure co-ordination with the MoD. Clearly, such a system might create a significant administrative overhead as Ofcom could be dealing with many users if the band were used for PMR/PAMR. Therefore, there might be some value in limited delegation of interference management to the band manager where this is possible, rather than requiring referral of every change back to Ofcom and ultimately the MoD. More generally, the prospect of attracting a private band manager may be greatly increased if Ofcom and the MoD can clarify how any future relationship would work and ensure that the coordination process was speedy with delegation of interference management to the band manager where feasible.

The possibility of dealing with a private band manager is also a source of uncertainty for small PMR users used to dealing directly with a government body and current administrative incentive pricing (AIP) arrangements. They may require assurances that a band manager will have adequate powers to resolve interference disputes and will not exploit lack of alternatives for users by setting excessive prices for access to spectrum.

3.1.3 Interference coordination, including Fylingdales

Any new uses of this spectrum will need to be coordinated with existing uses of adjacent frequencies, either in the same or neighbouring bands. These include both domestic and international uses. Of these, the constraints

[18] Ofcom, January 2005, *Spectrum Framework Review – Implementation Plan*, p.30.

imposed by coordination with the Fylingdales radar are by far the most important.

The Fylingdales radar

The Fylingdales radar, situated in the North of England, imposes a significant restriction on use of this band. Base stations using the frequency range 420–425 MHz are subject to a coordination agreement to protect the radar, expressed in the form of a reference network of hypothetical stations at regular spaced intervals across the UK mainland. An exclusion zone of 40 km applies in the direct vicinity of the radar within which base station deployment is not permitted. Civil users will have to notify the intended location, power and frequencies of individual base stations to Ofcom, for coordination with the MoD.

This reference network forms the basis of the agreement with the MoD and so is unlikely to be subject to change in the near term. Ofcom have told us that they believe the reference network is not unduly restrictive compared with typical commercial requirements. However, we are concerned that the current reference network is based on a lightly loaded PAMR network. In particular, the density of base stations is low compared with the network which we know Airwave requires in the 380-400 MHz band to serve rural areas, owing to terrain. Looking forward, it would helpful to potential users if Ofcom can develop a new reference network which reflects PMR use of the band rather than a PAMR national network, in order to illustrate the number of assignments that could be supported in the band

There currently appears to be limited understanding amongst potential users of the implications of this reference network for commercial base station deployment. In addition, potential users may be uncertain about how the coordination process might work in practice and what delays it might cause, not least as processes for coordination with many PMR/PAMR users might need to be different to the previous arrangements with Dolphin. If Ofcom can improve potential users' understanding of the nature of the constraint imposed by coordination with Fylingdales and provide some comfort that the coordination process will work speedily, this may encourage demand. At present, there is a perception in the industry that the constraints imposed will significantly impact on the commercial viability of deploying systems in this band. Even given our residual concerns expressed above, this perception may be unduly pessimistic.

Other domestic uses

Spectrum below 410 MHz is used by the MoD and also by radio astronomers (406-410 MHz). There are a number of channels within the 410-430 MHz range used by the programme making community.[19] There is usage of the

[19] 425 MHz for point to point audio links, limited to certain areas in South West England, and 427-428 MHz for wide area talk-back systems in metropolitan areas.

433 MHz band by short-range devices in accordance with CEPT/ERC Recommendation 70-03. We understand that there was previously a short range device allocation at 418 MHz used for radio alarms (e.g. car key fobs) but that a decision was taken to withdraw this allocation following award of spectrum to Dolphin, owing to interference.

None of these uses appear to impose significant constraints on use of the available spectrum.

International coordination requirements

UK use of the 410-430 MHz band must be co-ordinated with Ireland and France to control interference in border areas. This process is managed through an MOU between Ofcom and the Irish and French regulators, the terms of which must be adhered to by all spectrum licensees in the bands in question. The MOU requirements place constraints on the maximum field strength that can be emitted from base stations located in UK coastal areas.

Northern Ireland

We understand that negotiations with the MoD are underway regarding use of the spectrum in Northern Ireland, which could be assigned separately from the rest of the United Kingdom. Ofcom and Comreg[20], its Irish counterpart, have indicated a possibility of an 'all-Ireland' licence being offered at some point in the future. We understand from Ofcom that the MoD would be prepared to consider any proposals that they make.

3.1.4 European use of the spectrum

Ofcom's preference is to award this spectrum on a technology and service neutral basis. However, there is some uncertainty whether Ofcom can proceed on this basis, given the existence of ECC decisions designating the band for narrowband digital land mobile PMR/PAMR and earmarking up to 2 x 2MHz spectrum for systems based on the European TETRA standard.[21] We understand that Ofcom is currently taking legal opinion on whether these obligations are binding, especially given the demise of the Dolphin network.

Under the new ECC Rules of Procedure, the United Kingdom is shown as having not implemented any of the ECC Decisions and for the purposes of

[20] ComReg, the Irish regulator, issued a consultation paper on 28 October 2004 entitled 'Wideband Digital Mobile Services in the 420 and 900 MHz bands' that makes proposals to licence wideband digital mobile data services in Ireland in the 410-430 MHz band.

[21] A number of ECC Decisions are relevant to this band: ERC/DEC/(96)04 on the frequency bands for the introduction of TETRA; ECC/DEC/(02)03 on the availability of frequency bands for the introduction of narrowband digital land mobile PMR/PAMR; and ECC/DEC/(04)06 on the availability of frequency bands for the introduction of wide band digital land mobile PMR/PAMR systems in the 400 MHz and 800/900 MHz bands.

this study, we have assumed that licences can be issued on a technology and service neutral basis. Obviously, definitive legal resolution of this issue would be of great benefit to potential users ahead of any new assignment.

The status of the band across Europe is also an issue for potential users, as this will affect availability of equipment for particular uses. Recent discussions in Europe in relation to spectrum for wideband digital land mobile data services in the 400 MHz frequency range have largely focused on the 450-470 MHz band, although there have been some discussions on the 410-430 MHz band (such as the recent ComReg consultation).

3.1.5 Relationship with other bands

The band is a potential candidate for relocating PMR users currently in the 450-470 MHz (UHF2) band. The current UK configuration of the UHF2 band is misaligned with Europe. This means that it is prone to continental interference, and existing users are tied to use of proprietary UK equipment. It also provides no scope for meeting new demands and facilitating new technologies. Although Ofcom has abandoned plans for administrative realignment of the UHF2 band, changes to spectrum use could still be achieved through market mechanisms (although this is no simple task, given that the band currently accommodates well over 10,000 wide area and on-site PMR assignments).

Realignment of these bands could potentially be achieved by private band managers if they were awarded responsibility for managing spectrum in both the 410-430 and 450-470 MHz bands. One reason why this may be commercially attractive is that the 450-470 MHz band may be more suitable than the 410-430 band for cellular or broadband technologies. Whereas most local/regional PMR/PAMR users would be unaffected by Fylingdales coordination constraints in the 410-430 MHz band, the lack of contiguous spectrum available nationwide is a significant deterrent for cellular and broadband uses. The 450-470 MHz band is designated entirely for civil use.

3.1.6 Public safety use and on-site demand

Ofcom has indicated that, for public policy reasons, they are considering whether some of this band might be reserved for (a) public safety use and (b) on-site PMR use. The most likely configuration in this case would be for 2 x 2MHz blocks to be reserved for the public sector users and 2 x 200kHz for narrowband on-site use. This route might be considered if it is believed that a market mechanism cannot be used to allocate spectrum efficiently to these users.

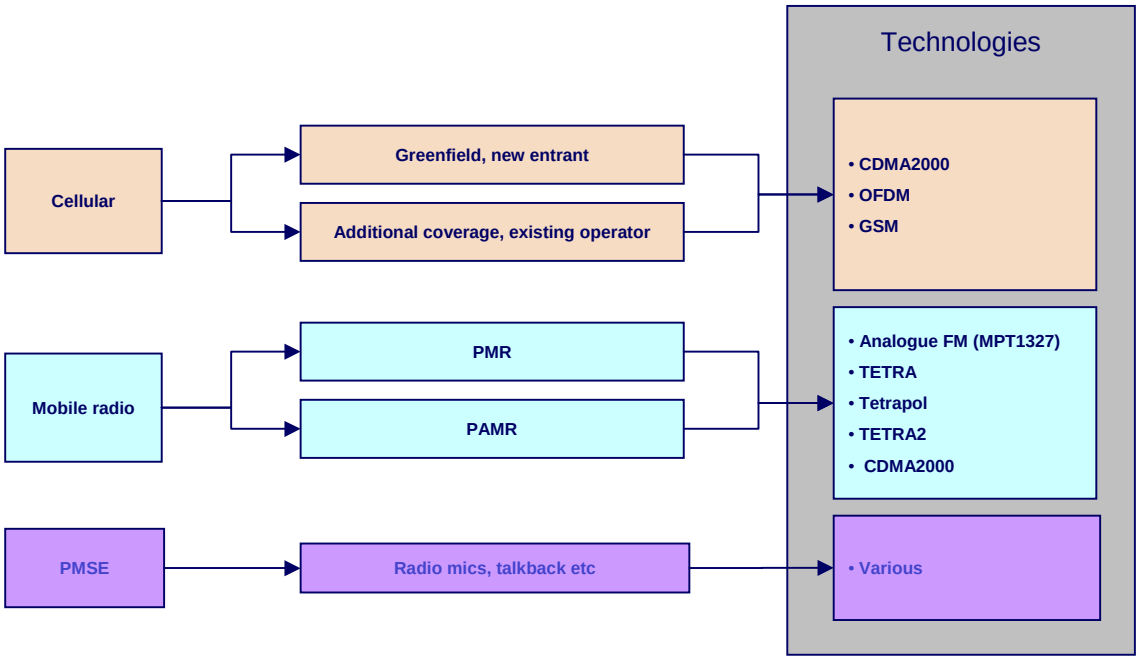
Potential public safety use accounts for up to half the available spectrum. Therefore, even if some spectrum is reserved for public safety use, there will still be a significant amount of spectrum available for private use in most parts of the country. Further, there would still be sufficient spectrum available for at least one private band manager, even if they were not given management rights to spectrum reserved for public safety. However, availability of spectrum for private use may be a problem in the area

immediately around Fylingdales, where MoD restrictions will preclude use of some channels available elsewhere. In this area, there may be little spectrum left for private use if public safety users are given precedence.

3.2 Potential future uses

The range of candidate uses depends to a great extent on the configuration of the spectrum that is made available. Figure 3 illustrates the range of principle candidate uses assuming that Ofcom is able to eliminate fragmentation of the spectrum. Many of the wide band uses identified require contiguous spectrum of at least 2 x 1.5MHz (or greater) and up to 1 x 5MHz for a single channel. If the spectrum remains fragmented, as with the assignments to Dolphin, possible uses may be limited to narrow band technologies fitting the 10 MHz duplex arrangements. These include TETRA, other analogue and digital PMR/PAMR technologies and compatible applications for PMSE, but exclude cellular and FWA applications.

Figure 3: Candidate uses for the 410-415 MHz & 420-425 MHz band



3.3 Demand assessment

A number of parties expressed interest in acquiring usage rights for this spectrum. All of them envisaged deploying technologies compatible with PMR/PAMR, and their requirements were geographically fragmented. We have not identified any organisation that is seriously contemplating use of the spectrum for the deployment of national mobile/broadband services. Only one respondent expressed a current interest in becoming a band

manager, although others may consider such a role if it was more clearly defined.

Principal interest in the band arises from two sources:

1. demand for additional UHF spectrum for on-site and wide area PMR usage in London and other major conurbations, especially for the introduction of digital technologies (e.g. TETRA, DMR and Compact TETRA); and
2. demand from Airwave to supplement its existing 380-400MHz allocation.

Additionally, there may be some demand for spectrum for deployment of localised PAMR networks; and interest from the PMSE community, as a possible source for replacement of lost spectrum in other bands (e.g. VHF Band III).

Parties involved in mobile and FWA networks cited a variety of reasons why this band did not interest them. These included lack of spectrum (maximum of 2x4MHz available), current fragmentation of the spectrum, geographic restrictions owing to MoD use, lack of control over the spectrum owing to requirements for military coordination, and concern that tolerated interference levels would not be sufficient to support a dense/heavily loaded network of base stations required of a national public network. Some of these factors relate to uncertainties (or incorrect expectations) that Ofcom could ease in advance of assignment. However, we found no evidence that this would facilitate renewed interest in the band from such users in view of the limited amount of spectrum that is available.

The interviews highlighted a number of key issues relevant to allocation and assignment:

- *Configuration of spectrum.* With the exception of Airwave, demand from individual spectrum users is for a number of channels in one or more specific geographic area(s). Whilst reconfiguring the band to 2x4MHz of contiguous spectrum is perceived to be valuable, we have not identified any value in reconfiguring the band to release a continuous 1x8MHz of spectrum, and have identified dis-benefits of doing this owing to the non-standard nature of the duplex arrangement that would result. Industry preference is to maintain the standardised European base transmit / mobile transmit configuration to maximise the range of available equipment for use in the band.
- *Uncertainty about Fylingdales and the role of the MoD.* Interviewees did not have a clear picture of the actual constraints imposed by Fylingdales, and were concerned about the timescales involved and the process for interaction with the MoD. We understand from Ofcom that the limitations that Fylingdales imposes on use of the band are less

onerous than current industry perceptions suggest.[22] Ofcom also indicated that they envisage continuing to manage relations with the MoD on behalf of all civil users for the foreseeable future. Greater clarity from Ofcom on these issues may therefore correct perceptions and remove uncertainty.

- *Scope for a band manager*. Although a number of organisations expressed interest in the concept of becoming a band manager, all but one said that they were not ready to take on this role at present. There was strong consensus that Ofcom should work together with the industry to develop the 'band manager' concept, including clarifying their legal rights, e.g. in relation to enforcement in the event of interference disputes. There were also specific concerns about managing this particular band, in relation to coordination with the MoD over Fylingdales. One organisation proposed that if the 410-430MHz band was made available for private band management, this should be done in parallel with the 450-470MHz band, in order to facilitate band realignment.
- An additional obstacle to the entry of band managers is the concerns of their potential customer base. PMR users indicated concern about the management capabilities of such organisations and a specific fear that they may be subjected to price increases if they are tied to spectrum controlled by a private entity. We consider this issue further in Section 3.5.2.

3.4 Viability and value of potential uses

As agreed with Ofcom, our modelling exercise focused on the viability of introducing one or more private band managers for this spectrum. We have not attempted to model the value of actual PMR/PAMR use (or other complementary uses such as PMSE), as this should not be affected by the introduction of a band manager. Further, we have not attempted to model a public mobile/broadband system using this spectrum, as our demand assessment did not identify any interest in such activity.

Our main finding is that band management models appear viable for this band, assuming that users are willing to submit to private management.

[22] Industry perception may have been influenced by the current rejection of many wide-area PMR systems in the 430-450 MHz band by the interference prediction algorithm used to coordinate with MoD use. We understand from discussions with Ofcom that the current process still assumes that the Dolphin network is present. Once this has been corrected, Ofcom has indicated that most of the proposed PMR wide-area systems would probably be allowed. This approach has been used by Ofcom to ensure that the future availability of the spectrum once used for that network is not prejudiced by the establishment of new systems in the 430-450 MHz band.

There may also be scope for more than one band manager.[23] However, the current value of the spectrum for band management is depressed by uncertainty over the Fylingdales issue and actual demand for assignments from users. Both these uncertainties may be resolvable by Ofcom, for example by demonstrating that coordination of commercial uses with the MoD can be achieved successfully. Therefore, a delay in the introduction of band management (but not to assignment to end users) to say 2009 could significantly increase perceived value and interest from the private sector.

This finding is more optimistic than a previous study by Webb and Cave (2003) which found that the business case for a PMR band manager was "*somewhat fragile*".[24] However, that study focused on existing analogue PMR bands and assumed that a band manager would have to buy out existing users, rather than buying unencumbered spectrum in an auction. It concluded that a band manager would require at least 2x4MHz and need to raise efficiency of use by at least 40% to be profitable. The authors questioned whether a private band manager would be capable of realising this level of efficiency gain relative to a regulator, given that they "*expect regulators to strive to reduce pricing and to become more efficient*".

3.5 Competitive implications

3.5.1 Structure of demand

All existing demand identified in our interviews is for multiple PMR/PAMR channels, or compatible technologies. There was one potential user that required spectrum in multiple locations nationwide; other potential users required spectrum in specific areas. As would be expected, demand appears greatest in urban areas, but there is no simple geographic pattern, such as clearly delineated regional demands.

For these types of users, fragmentation raises coordination costs but does not make their services infeasible. Availability of spectrum with the existing 10MHz duplex spacing is essential to avoid user tie-in to proprietary UK equipment solutions, which could be expected to diminish demand for the spectrum from users. The attractiveness of the spectrum would be increased by Ofcom reducing fragmentation through negotiation with the MoD; however, this is not a prerequisite for successful assignment, providing existing duplex arrangements are maintained as all observed demand was for uses with narrow carriers.

[23] This could complicate interference coordination with the MoD and again suggests that future work will be needed to clarify the roles and responsibilities of the MoD, Ofcom, band manager(s) and users.

[24] Webb and Cave, Dec 2003, *Band Managers – The policies and incentives needed to make them succeed*, Papers in Spectrum Trading No. 3, Warwick Business School.

The presence of many small users creates problems for the packaging of usage rights. If spectrum is assigned in large blocks of frequencies, small users may lose out relative to bidders desiring large blocks even though their collective value is higher. This is because they may find it difficult to amalgamate their demand. The costs of potential trading partners identifying each other and concluding a transaction may be significant relative to the gains from trade generated, though this may in turn create an opportunity for a band manager to aggregate small users' demands. The costs of trading relative to likely efficiency gains are a potential impediment to the function of both the primary assignment and the secondary market.

This specific issue could be addressed by assigning spectrum in small blocks, for example on a transmitter basis. However, this is an imperfect solution as it may create aggregation risks for larger users, who may need a large collection of such rights to deploy services (this may be a particular problem for PAMR operators needing spectrum to cover a specific service area). Further, if usage rights are assigned directly to many small users, it may be difficult for them to amalgamate spectrum or change use in the secondary market, owing to the large number of parties that might then be involved. For example, once allocated on the basis of transmitter licences, it may be largely impossible for the secondary market to switch usage over to a wideband application. For this band, the lack of current interest from mobile or FWA players means that this problem is less acute, but this is not a sufficient justification for foreclosing future options for change of use if these could be maintained.

An alternative approach is to allocate the spectrum to a band manager, who should be better able to trade off the needs of both small and large users, and current and potential future uses. Band managers would also be better equipped than small users to address the on-going issue of managing interference efficiently with parallel military uses. Although Ofcom could itself fulfil the role of band manager, transferring this function to private parties should, in principle, maximise the scope for innovation. However, the limited interest of our private sector interviewees in taking on the role of band manager casts doubt over the immediate viability of this approach.

One further complication in relation to the structure of demand for this spectrum is the existence of public sector demand, including emergency services and regional transport networks, which may offer social benefits significantly in excess of the users' ability to pay for spectrum. Ofcom's general preference is that public sector demand issues are addressed at the service level (e.g. through transparent subsidies) rather than through intervention in spectrum markets. However, absent such action at the service-level, Ofcom may have to take an administrative decision to allocate spectrum directly to public safety users.

It is beyond the scope of this study to estimate the social benefits of allocating some of the available spectrum directly to public safety use rather than have such users compete in an auction. However, we note that maximum public safety demand appears to be only around half the available

spectrum. Thus, there will still be scope for private use of the band even if some spectrum is reserved for public safety use.

3.5.2 Competition issues

The assignment of this band has the potential to affect competition, as spectrum suitable for digital PMR is currently scarce. Digital PMR has the potential to provide rather different services to existing analogue PMR and they are imperfect substitutes; digital PMR has significant additional functionality. Indeed, unless and until the 450-470 MHz band is realigned, this may be the only band where equipment for digital PMR can easily be obtained and deployed. This raises two specific issues:

- whether a single band manager would be able to exercise market power;
- whether there are any specific concerns about Airwave purchasing spectrum in this band given that its services may be an alternative to self-provision of PMR using this band.

Taking the question of band manager market power, there must be a reasonable presumption that the lack of alternative spectrum for digital PMR in the near- to medium-term and the lack of close substitute services would mean that a single band manger would have a dominant position and be able to raise its fees to inefficient levels.

Although Airwave operates a PAMR service, the large majority of users will not find this a reasonable alternative to self-provided digital PMR services. First, Airwave is currently under an obligation to restrict its supply of services to emergency services and public safety agencies on the sharers' list. Whilst it is possible for this list to be extended by application to Ofcom, organisations must have a public safety remit. Second, even without the restriction arising from the sharers' list, the Airwave service has a high degree of reliability, resilience and security that commercial users would be unlikely to be prepared to pay a premium for relative to self-provided PMR services. For some users, self-provided PMR will provide additional flexibility to configure the characteristics of the services relative to using PAMR.

Given this lack of alternatives, the only way in which an effective constraint on the band manager's pricing could arise would be if:

- potential users anticipated the ability of the band manager to set excessive prices (especially if users were locked in to using the band owing to sunk costs of equipment purchase); and
- users were able and willing to continue using analogue PMR systems in other bands rather than switching to digital systems.

Note that we require both conditions to be true for there to be an effective constraint on pricing. If potential users lack foresight, there is a danger that a dominant band manager could initially set reasonable prices, attract users who make committing investments to use the spectrum and then raise prices subsequently.[25]

There is an interaction with future realignment plans for the 450-470MHz band. Clearly, if the 410-425MHz band were allocated to a dominant band manager, this would create an inefficient disincentive for migration from 450-470MHz to 410-425MHz. Conversely, if there were at some point compulsion on users to migrate from 450-470MHz, this would simply increase the market power of the band manager, as users would lose an alternative option. Therefore, it is important to ensure that a band manager does not have market power in order to facilitate migration from 450-470MHz.

Competition law always acts as a constraint on the abuse of a dominant position, not only providing redress ex-post but also giving an ex-ante incentive not to abuse such a position. There are various powers open to Ofcom to address competition concerns (the Competition Act, Communications Act, Enterprise Act and spectrum management powers). Nevertheless, competition law alone may not be sufficient to address these potential problems. In particular, there is a danger that with a single band manager there would be little demand for users for access to spectrum, as users only have ex-post protection if the band manager raised fees once users had invested in band-specific equipment. Given that we have already identified the business case for a band manager to be feasible, but not strong, such worries on the part of users could undermine the viability of band management.

At the same time, it is important not to overstate these concerns. Clearly if such problems exist, there are also commercial incentives for a band manager to try to commit to a path for its future prices to provide users with some assurance that they will not be subject to price increases once they have made investments in equipment. The band manager could do this by offering long-term contracts specifying future prices. However, even in this case, a dominant band manager may still set prices that are above efficient levels.[26]

Given these concerns, there is a strong case to consider multiple band managers for this band providing this is feasible. Our analysis suggests that there is a business case for a band manager with 2 x 2MHz of spectrum and possibly even less. Therefore, if there were no separate reservation of spectrum for public safety bodies, it appears feasible to have at least two

[25] This is an example of the so-called hold-up problem.

[26] See Farrell, J., and Shapiro, C. (1988), "Dynamic Competition with Switching Costs", RAND Journal of Economics, 19: 123-137.

competing band managers. If 2 x 2MHz were reserved separately, then it may not be possible to have more than one band manager.

A somewhat related issue is the role of Airwave, as the provider of services that are the closest substitute to self-provided digital PMR using this band. At present, we do not believe that any involvement by Airwave in this band would raise any competition problems because of the sharers' list. This arrangement currently prohibits Airwave from offering commercial services using its 380-400 MHz frequencies. Therefore, there is little competition between Airwave and self-provided digital PMR services. A possible exception to this might be users who have a limited public safety function and so are (or could be) on the sharers' list, but who do not need the extra features of the Airwave network (such as encryption and high resilience); water companies might be a possible example. For such users, there may be a choice between self-provided PMR (or even localised PAMR using this band, if this became available) and using Airwave. However, those users with an effective choice between Airwave and self-provided digital PMR are likely to be a small fraction of all users. Therefore, the competitive interaction between Airwave and self-provided PMR is small. Given this, there can be no significant anticompetitive effect from any Airwave involvement in this band.

Clearly this conclusion rests entirely on the fact that Airwave is prevented from competing for commercial customers by the sharers' list. Relaxation of the sharers' list restriction could possibly increase competitive interaction between Airwave's TETRA offering and self-provided digital PMR and so raise some concerns *in principle* about Airwave's involvement with this band. In particular, there might be a fear that if Airwave were the sole manager of this band, then it would control the closest substitute to its existing TETRA network.

Again, it is important not to overstate these concerns. First, there is no suggestion at present that the sharers' list would be significantly further extended. Second, Airwave itself needs to maintain high service quality standards for public safety organisations, which limits the extent to which it could compete for general commercial business even if the constraint created by the sharers' list were absent. Third, even without the sharers' list restriction, it is by no means clear that the Airwave service would lie in the same economic market as self-provided digital PMR or even other PAMR services, owing to the specific characteristics of Airwave's service (reliability, encryption etc). This question of market definition would require further specific investigation to resolve, which lies outside the scope of this study.

Given these considerations, we believe that there is no case for excluding Airwave from purchasing spectrum in this band or operating as a band manager, providing the sharers' list restrictions are expected to remain in place for the foreseeable future. Indeed, Airwave has some capabilities (such as experience with operating TETRA and dealing with government) that may make it well-placed to operate as a band manager for this band.

3.6 Packaging of spectrum

The SFRIP envisaged three options for packaging the spectrum: a single nationwide block; a number of regional blocks; or bespoke licences on a FCFS basis (channels, licensed by transmitter). We have added one further option: splitting the spectrum into 2-4 nationwide blocks. Ofcom's Plan also considers the possibility of reserving some spectrum for public safety use.

Table 2 summarises our assessment of these options. The only option that we have explicitly ruled out is that of regional licensing. This is because there is no clear basis for geographic division of the spectrum[27], and the creation of arbitrary boundaries could impede efficient use and increase interference coordination costs.[28] By contrast, splitting the spectrum into multiple blocks of national channels would not create any substantial coordination concerns. Further, this could facilitate entry of competing band managers, so may be a superior option to a single nationwide licence if sufficient spectrum is available.

The main objection to issuing nationwide licences is the apparent lack of demand for spectrum packaged in this way, given that actual demand is for local and wide-area PMR/PAMR and demand from prospective band managers is unproven at present. If the spectrum were allocated in this way now, there is a risk that the licence(s) might not be sold or that there may be few bidders (which may raise competition concerns). However, this situation may change if and when Ofcom makes progress in clarifying how the band management model would work.

In the short term, licensing on a transmitter basis would ensure actual users get access to the spectrum as quickly as possible. This does not rule out the possibility that nationwide band management licences could be allocated later, encumbered by existing assignments. Indeed, having a pre-existing customer base may increase the attractiveness of band management. However, users would need clarity about whether they might be subject to the imposition of a third party band manager at a future date. Therefore, policy about the future use of a band manager must be determined prior to allocating licences to users, even if a third party band manager was not initially used.

We view the assignment of spectrum to public safety uses as compatible with these approaches, as the type of use is similar, being based on PMR/PAMR operation. Public safety users could fall under future private sector band managers, providing a substantial client base. They could also

[27] With the possible exception of the creation of a specific licence for Northern Ireland, as the main coordination concerns here are with the Republic of Ireland, not Great Britain.

[28] Interference problems and coordination are highly dependent on topography, so administratively predetermined boundaries are unlikely to be very efficient.

be managed separately, although this would obviously reduce availability of spectrum for private management, potentially reducing the number of viable private sector managers.

Table 2: Packaging options for the 410-415 & 430-425 MHz bands

	Comments	Assessment
Regional licences	Could facilitate metropolitan (London) use and creation of all-Ireland licence Geographic regions determined by political and administrative boundaries could impede efficient use and increase costs of interference coordination	✗
Single nationwide licence	Would allow both large users and prospective band managers to compete for spectrum in an auction Only one likely bidder identified to date Potential competition concerns if there is just one band manager	✓?
2-4 nationwide licences (blocks of channels)	Could facilitate competing band managers – but may complicate negotiations with the MoD over fragmentation Large regional users may be more likely to participate, as could sell excess spectrum in secondary market Only one likely bidder identified to date	✓?
Channels, licensed by transmitter	Would facilitate assignment to small users and urban transport bodies, but could prevent nationwide use owing to aggregation problems Auction would be complex	✓?
Reserved spectrum for public safety	Public safety bodies do not require all the available spectrum Licences could be sold encumbered by allocations to key public safety bodies To ensure efficiency, these licensees would need to pay opportunity cost	Compatible with other approaches

3.7 Suitability of auctions

Historically, spectrum for PMR-type services have been assigned on a FCFS basis. Charges have been set to recover administrative costs, augmented by administrative incentive pricing (AIP) in particular geographical areas where demand would otherwise outstrip supply ('hot spots').

FCFS works satisfactorily only if there is no excess demand for spectrum with prices set for administrative cost recovery (i.e. there is no economic scarcity), which is clearly a highly unrealistic scenario. Otherwise, some market (i.e. price-based) or administrative rationing scheme will necessarily be required to limit or select between competing demands. Although FCFS can be augmented by AIP in order to choke off excess demand, this is unlikely to produce particularly efficient results. Owing to imperfect information about the value that potential users might place on spectrum, it is very difficult for a spectrum authority to set AIP at a market clearing level:

- Setting AIP too low will mean that FCFS acts as a rationing mechanism, with more demand for spectrum than the available supply. The primary allocation would not be efficient, as there is no guarantee that those first to request spectrum will necessarily be those with the greatest value for it. Therefore, we are reliant on the secondary market to ensure efficient allocation. There would be windfall gains for inefficient acquirers of spectrum in a FCFS process who could then resell it at a premium. These gains may, in turn, attract speculative demand in the FCFS process.
- Setting AIP too high chokes off demand unnecessarily and means that some users who could efficiently use the spectrum will be priced out.

Therefore, the use of FCFS with AIP is very much a second best. Auctions have the clear advantage that they can reveal information about users' valuations that would otherwise remain unknown. However, there are also a number of problems with the use of auctions in this band that also need to be considered:

- If the spectrum is assigned on a transmitter basis, an auction would be theoretically possible. However, it would be very complicated, as the selection of winning bids would need to take account of location and power thresholds, not just willingness to pay. There are also two separate sources of spectrum scarcity that must be considered: interference between neighbouring users; and interference with Fylingdales created by the totality of users. As we discuss in the next subsection, there may be scope for reducing complexity by only using auctions to resolve demand conflicts in hot spots areas. Nevertheless, whatever process is used, it would be difficult to trade-off the demand of an aggregator (e.g. a prospective band manager) with the demands of many small users.
- If the spectrum is assigned as one or more national licences, an auction would be feasible and simple. However, there is no proven demand for spectrum aggregated in this way. Given the difficulties for small users to aggregate their diverse demands, it is unlikely that an auction of national usage rights could deliver an efficient outcome without the participation of a band manager to act as an aggregator. The role and responsibilities of a band manager are currently unclear, and demand to take on this role is uncertain. Substantial progress would need to be

made in resolving these issues to make an auction for national licences appropriate.

We explore auction options under both the transmitter and national licensing approaches in the next subsection.

3.8 Auction / assignment options

On the basis of our assessment of packaging options, we have identified two possible assignment approaches which Ofcom could undertake:

- *Option 1: Transmitter licensing*. The spectrum could be licensed by transmitter on a FCFS basis, with either geographically differentiated AIP to choke off excess demand or, if possible, a sealed-bid auction element to resolve competing demands in hot-spot areas.
- *Option 2: National licence(s).* Ofcom could auction one or more national licences (depending on the availability of spectrum following any award to public safety users).

We explain each option in detail below. Our preferred way forward is option 2, providing practical difficulties in implementing the band management model can be overcome. It is the simplest to implement, and should allow greatest flexibility for competition between different types of use both at the primary assignment stage and in the secondary market. However, the viability of this approach depends on there being demand from parties willing to take on the role of band managers; otherwise there may be inefficient delay in bringing spectrum to PMR/PAMR users relative to Option 1. Firm evidence of such demand is currently lacking. Nevertheless, there are reasonable grounds for believing that private interest in band management will increase once Ofcom has clarified the role of the band manager, in particular in relation to interference coordination and policing, and competition concerns.

3.8.1 Option 1: Transmitter licensing

We have identified three approaches for assigning spectrum licence by transmitter, as summarised in Table 3:

- *First come first served*. Ofcom could continue with the traditional approach of FCFS for PMR assignment, augmented by AIP and possibly a lottery for assignments in 'hot spot' areas of high demand. A lottery could be used as a backstop if the level of AIP for hot spots were set too low and there was still excess demand. This approach is straightforward to implement but may not produce particularly efficient outcomes in the first instance, though hopefully the secondary market could then come into play.
- *Complex, national sealed bid auction*. Ofcom could develop an auction format that is full integrated with the planning tool used to identify interference constraints. Specifically, bidders could submit a schedule of demands specifying the location of licences and willingness to pay. A

software algorithm would be used to calculate the optimal configuration of licence awards that maximised total revenues without breaching interference constraints. There would be two forms of constraints arising from the need to protect individual users from harmful interference from neighbouring users and the need to ensure that the MoD's maximum power thresholds are not breached. The cost of the spectrum to users could be set based on a marginal price basis (i.e. the opportunity cost of denying the next strongest bidder). Such a process should theoretically produce the most efficient assignments, but might not be particularly transparent. In our view, it is possible to design such an allocation process and build software to run it. However, implementing a system capable of assessing trade-offs on a nationwide basis would be challenging and costly; the effort and expense is likely to be disproportionate to the efficiency gains realised.

- *Hybrid FCFS / hot spot auctions*. A practical compromise may be to develop a hybrid approach, using FCFS with administrative cost recovery where there is no excess demand and simplified sealed bid auctions for demand 'hot spots'. This could introduce market mechanisms without the complexity of the previous option. The idea would not be to consider the full complexity of all the interference constraints, but rather to make some reasonable simplifications to produce an approximately efficient outcome where market mechanisms could be applied independently at each hot spot location. We discuss this in detail below.

Table 3: Assignment options for licences allocated on a transmitter basis

	Comments	Assessment
First come, first served	Traditional approach, straightforward for small users Requires AIP to promote efficient assignment but AIP is difficult to set efficiently, especially with varying regional demand Lottery may be required to distinguish competing demands in hot spot urban areas even with AIP Need to allocate Fylingdales interference budget back to geographical areas to be able to define demand hot spots	✓?
Complex national sealed bid auction	Bidders submit schedule of demands specifying location and willingness to pay Auction software determines optimal set of bids nationwide, taking into account of all relevant interference constraints Full range of trade-offs in meeting the Fylingdales interference constraint can be considered, so outcome should be reasonably efficient Complex algorithm would require bespoke software and so might not be transparent Design and implementation costs may be too great relative to the efficiency benefits generated	✗
Hybrid FCFS / hot spot auctions	FCFS with administrative cost recovery used to assign spectrum in all areas except hot spots For hot spots, bidders submit schedule of demands specifying location and willingness to pay. Auction determines assignment, but each hot spot can be considered separately, unlike the complex national auction option Need to allocate Fylingdales interference budget back to geographical areas to be able to define demand hot spots, so some national trade-offs not considered Cost and complexity of software should be much reduced relative to nationwide auction Outcome is more transparent than national auction	✓?

If Ofcom adopts a FCFS approach, the main challenge will be setting appropriate levels of AIP that should ideally vary geographically. Ofcom has already undertaken work on applying AIP to PMR users that is relevant here.

However, in applying AIP to this band, asymmetries in regional demand pose particular problems. Specifically, geographically uniform AIP is unlikely to be effective. There is no reason why the market-clearing price in one hot spot area should equal the market-clearing price in another hot spot area, as demand may be stronger in some areas than others. Using a two-tier pricing system (administrative charging where there is no excess demand with a uniform national AIP rate for hot spots) would risk choking off demand unnecessarily in some hot spots whilst at the same time still leaving excess demand in other hot spots.

In order to implement any such system, it would be necessary to allocate the overall Fylingdales interference budget to specific geographical areas; otherwise there could be no sensible definition of a localised demand hot spot. If the totality of demand across the country leads to too much interference for Fylingdales, there are various alternative ways of meeting the Fylingdales interference constraint involving users being eliminated from different parts of the country. However, in order to define meaningful demand hot spots, we clearly cannot consider tradeoffs between denying a usage request in one area of the country against denying a request in another area. Therefore, in order to implement hot-spot AIP for this band, it appears necessary to take a simplified approach, allowing defined geographical areas to make a certain predefined contribution to the overall interference level at Fylingdales. Ofcom already has considerable data on demand for analogue PMR services that could be used to undertake this task.

Unfortunately, there are no clear criteria for calculating differential AIP across regions. Thus, Ofcom may still be left be in a position where it faces excess demand in a hot spot and has to discriminate between some users. In such cases, Ofcom could assign spectrum in these areas by lottery. We would expect the secondary market to resolve inefficiencies resulting from the lottery, as this would only require trading within the hot spot area. This would substantially mitigate the problem of transaction costs arising from the difficulties of identifying trading partners. Lists of lottery winners and losers could be published to facilitate trading. However, this process would create windfall gains for lottery winners and would constitute a lost opportunity for the public sector in securing revenue from the granting of scarce rights. There is little reason to expect a lottery to produce a significantly different outcome to FCFS, except that the former avoids the need to identify when valid applications for spectrum were received and so may reduce administrative overheads.

Rather than using AIP to resolve competing demands in hot spots, it is worth considering whether it is possible to bring in a market mechanism, but without incurring the complexity of a unitary national auction considering all the possible trade-offs in meeting the various interference constraints. For example, bidders could be invited to submit a sealed bid that is used to resolve competing requests in hot spots. This would only come into play in areas where there was excess demand. Such a system could be used alongside a reserve price, which would be analogous to AIP arrangements.

This arrangement would be simpler than running one large auction, as it would be possible to resolve competing demands area-by-area, rather than needing to consider trade-offs across the entire country. However, as with the use of AIP, it would be necessary to allocate the Fylingdales interference budget back to geographical areas; otherwise it is impossible to take an area-by-area approach.

Consider a simple example. Suppose with administrative cost recovery, demand exceeds supply in Manchester and London. Suppose additionally that we can allocate the interference budget with respect to Fylingdales to Manchester and London individually (so for the moment we ignore the fact that the constraint might be met with more users in London and fewer in Manchester or vice versa). In this case, it is possible to use a market mechanism to resolve competing demands in Manchester irrespective of the position of London and vice versa. This is an enormous simplification relative to running a national auction considering all trade-offs.

Clearly, we are assuming that the primary limitation on meeting demand is interference between neighbouring users, rather than with Fylingdales. However, this is probably a reasonable assumption for large areas of the country. If this speculation is correct, the loss of efficiency caused by not considering the trade off between different areas in contributing to interference at Fylingdales would be modest.

3.8.2 *Option 2: National licence(s)*

For the assignment of nationwide licences, there are two auction formats that could be used: a sealed bid; or ascending bid format. Both would be straightforward to implement. Table 4 summarises the relative advantages and disadvantages of the two approaches. There is little to choose between them. Auction theory tells us that an open process may produce a more efficient outcome in a common value setting, but that a sealed bid may be more robust to low competition scenarios.[29] The preference indicated for a sealed bid reflects a general concern that competition for national licences, either from prospective band managers or other potential users, may be weak, and a specific concern that bidders may be asymmetric. This assessment might change if there was a significant upsurge in interest in band management prior to the assignment of rights.

The detailed rules of the auction will also depend on the number of lots available, Ofcom's perception of the viability of having more than one band manager, and whether any bidders who would use the spectrum for purposes other than band management are expected to participate. In the case where Ofcom perceives that only one band manager is viable, then presumably there will be only one licence and the auction rules will be

[29] See Section 2.2.3 for further explanation.

particularly straightforward. If Ofcom perceives that more than one band manager may be viable, then there would be at least two lots. In this case, bidders may face substitution or aggregation risks, which would need to be addressed in the auction rules[30]:

- With a sealed bid for two lots, bidders should be allowed to submit two mutually exclusive bids, one for each lot, in order to resolve substitution risks. In an SMRA, this problem is resolved by allowing switching between lots over multiple rounds.
- With either a sealed bid or SMRA, bidders should also be allowed to submit bids for *both* lots. A possible exception to this would be if Ofcom has competition concerns about all spectrum being assigned to a single band manager. In this case, it could restrict bidders to one lot each (e.g. as in the case of the UK 3G auction). Note that this approach may be undesirable as it would effectively prohibit participation by a non-band manager wishing to use all available spectrum. Further, any restriction on bidding on two lots may be redundant if bidders can still acquire both licences in the secondary market.
- If Ofcom is uncertain about the viability of having more than one band manager, it may also consider allowing bidders to submit combined bids for both lots. This would mitigate aggregation risks, but at the risk of unduly favouring an aggregator over band managers willing to take on smaller spectrum blocks.

In the plausible case where only aspiring band managers bid for the spectrum but there is competition, then the final price in the auction should reflect the scarcity value of the spectrum for end users, less the costs of band management. We would not expect to see band managers earning any excess profits, as these would be competed away in the competition to become a band manager in the auction. Note that this conclusion holds even in the case that there was a single dominant band manager able to set excessive prices for users; this would be reflected in the price that the bidder would be prepared to pay for the right to be a band manager.

If, additionally, there were little or no competition between potential band managers, it is much more difficult to see how to organise the assignment process. First, this situation could lead to a band manager with market power with respect to charges for end users. Second, lack of competition to become a band manager may mean that scarcity rents are not reflected in an auction price and passed back to the government. A partial solution is to set a high reserve price in any auction process. This can extract some of the scarcity rents, though the ability to extract these rents depends on the

[30] The following bullets are based on the assumption that the lots have distinct characteristics; if the lots were sufficiently similar that they could be treated as identical, somewhat simpler auction rules could be applied.

precision with which they can be estimated; if they are very uncertain, it is difficult to set the reserve price and a cautious approach that minimises the risk of unallocated spectrum will certainly leave some of the scarcity rent with the band manager. In addition, it may be possible to ensure that any band manager is at least as efficient as Ofcom by setting a reserve price at the level of charges that Ofcom would otherwise have expected to earn.

Table 4: Assignment options for licences allocated on a nationwide basis

	Comments	Assessment
Sealed bid	More robust to low competition / strong bidder scenario Could be preceded by ascending bid stage if more than two bidders For multiple blocks, may be benefits from a combinatorial aspect to allow bidders to express preference for different numbers amounts of frequency	✓
Ascending bid / SMRA	Ensures assignment to strongest bidders (efficient outcome) Vulnerable to low competition / strong bidder scenario Might be an alternative for assignment to band managers if demand for the band manager role increases over time	✘

Band management with an upfront spectrum charge would be capital intensive. There is, therefore, a strong case for allowing successful bidders to spread the auction payment over a number of years, rather than charging an upfront fee. Ofcom could either define a deferred payment structure prior to the auction or invite bids on the basis of a range of payment structures (which would then be traded-off on the basis of an agreed discount rate). An alternative approach would be for Ofcom to invite bids on the basis of revenue sharing, as was used for the Hong Kong 3G auction. This approach would significantly mitigate risk for private entrants. However, we view revenue sharing as less attractive than deferred payment of auction fees, as such as approach may distort incentives for private operators and would force Ofcom to take an active role in monitoring the band manager's business performance.

The public sector's cost of capital is likely to be lower than that of a private bidder, so its opportunity cost of foregoing revenues now should be less than the benefits to the private party from being able to spread payments over time. Moreover, given the current market uncertainty over the viability of band management, allowing deferred payments would reduce risk for

bidders and make it easier for them to attract financial backing. This, in turn, may increase the number of bidders and increase auction revenues, which would provide compensation for Ofcom for effectively taking on some of the risk associated with development of the private band manager.

3.9 Timing

There is existing demand for this spectrum from multiple PMR-type users. Further, our market assessment has found no evidence of future demand for the spectrum that could both have a higher value and conflict with existing demand. Therefore, the spectrum should ideally be made available to users as soon as practically possible, i.e. within the 2005/06 timetable envisaged in the SFRIP.

Prior to assignment, it would be beneficial to users for Ofcom to clarify a number of issues, including:

- the outcome of discussions with the MoD on the scope for reconfiguring available spectrum;
- the exact nature of the interference constraints created by Fylingdales;
- updating the reference network to reflect the most likely use, i.e. localised PMR transmitters rather than a national PAMR network; and
- any plans that Ofcom may have for introducing private band managers for this spectrum.[31]

Our preference for national licensing (option 2 in the previous section) requires that Ofcom can move quickly to develop a clear framework for band management. If the process of developing a band management framework and 'marketing' the associated model (to both bidders and PMR end users) resulted in slippage beyond the 2005/06 timetable, then the costs of delay (in terms of denying access to PMR users) may be too great to justify this approach. It should be noted that proceeding with a transmitter-based licensing approach would not preclude the transfer of band management rights from Ofcom to a private party in the future, provided that licensees were made aware of the possibility that spectrum could be subject to future band management at the time of primary assignment (although any uncertainty over whether and under what terms band management might be introduced could limit initial demand for spectrum from individual users). Further, in the event that Ofcom does not identify any clear demand from private parties to take on the band management role, it might consider developing its own autonomous management units than can in due course be spun off into the private sector.

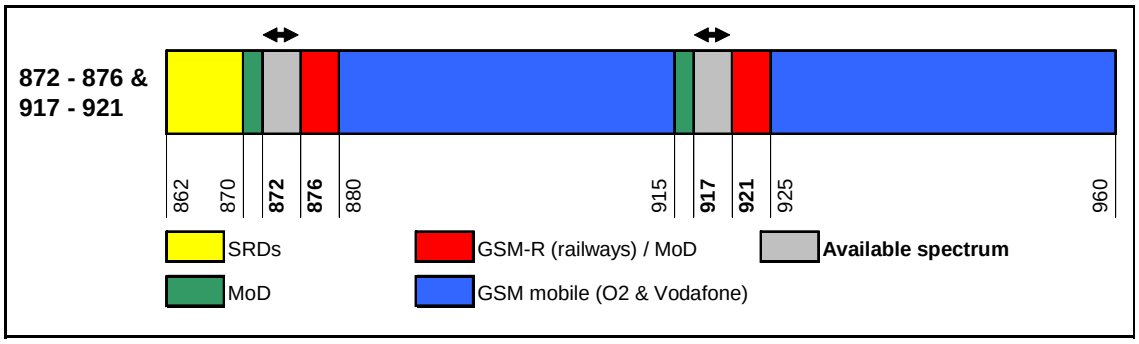
[31] It would also be helpful to potential bidders and end users if Ofcom can clarify what plans, if any, it may have for introducing private band management in the 450-470MHz band.

4 The 872-876 MHz & 917-921 MHz band

This band consists of 2 x 4MHz of contiguous spectrum with a 45 MHz duplex spacing: 872-876 MHz paired with 917-921 MHz. The spectrum is available nationwide. The location of the spectrum and neighbouring uses are illustrated in Figure 4.

Frequencies in this band were previously allocated to Inquam Holdings Ltd / Dolphin Telecommunications Ltd for the provision of a TETRA2 overlay system to their nationwide TETRA system. The licence was revoked in July 2004, after the operating company went into administration. At the time of the revocation, no network had been rolled out using this band.

Figure 4: The 872-876 & 917-921 MHz bands and adjacent spectrum



4.1 Availability of spectrum and constraints on its use

Our study has identified a number of factors that impose significant constraints on the use of this frequency band. The most important appear to be the limited amount of spectrum available and the coordination requirements necessary to prevent interference with adjacent GSM mobile use. These constraints effectively rule out the use of certain technologies in the band, and will also detract from the viability of others.

In the following paragraphs, we summarise these and other constraints on the use of the band, and identify sources of uncertainty for potential users.

4.1.1 Availability of spectrum

As with the 410-415 & 420-425 MHz band, the amount of spectrum available is modest - just 2 x 4MHz. As we discuss below, this means that the scope for deploying wideband applications is highly constrained.

The attractiveness of the spectrum might be increased if it could be amalgamated with adjacent spectrum. In principle, this could be achieved through trading with either the MoD or railways, the institutions that have the rights to use the adjacent spectrum (also paired). However, potential users have no reason to believe that this spectrum will be available in the

foreseeable future, as it has not been liberalised (as yet) and there is no evidence that the current occupants would be willing to vacate the spectrum.

We understand that the GSM-R band is not currently operational although trials are being undertaken at a number of locations as part of longstanding plans to deploy GSM-R in the band in line with the common allocation of this spectrum across Europe. The MoD use their spectrum for tactical radio links.

4.1.2 Interference coordination with neighbouring bands

Any use of this spectrum would need to be coordinated with neighbouring uses. The most important constraint here (as the GSM-R spectrum is not currently used) is coordination with Vodafone and O_2, who use the 880-915 MHz and 925-960 MHz for second-generation (GSM) mobile services, in accordance with most of Europe and many countries worldwide. In particular, there is a difficulty with coordinating the upper block of available spectrum with the lower GSM block that may severely restrict use of this spectrum.

As illustrated in Figure 4, the upper block of the spectrum at 917-921 MHz sits adjacent to O_2's existing GSM base receive block at 910-915 MHz. The co-incidence of base transmit frequencies (at 917 MHz) with base receive frequencies (at 915 MHz) could cause severe interference to O_2.

The scope for overcoming the interference has been studied within the CEPT with a view to determining appropriate conditions for use of the 917-921 MHz band. Studies conclude that filtering will be required on all transmitters in the 917 MHz band and O_2 base receivers in the 915 MHz band, in addition to coordination of all base station sites in the 917 MHz band within a certain distance of existing O_2 base receiver sites.[32]

The CEPT results suggest that coordination is achievable. However, Ofcom has recently reviewed the study results and identified potential errors in the analysis. Its revised view is that either additional frequency separation or tougher constraints on transmitted power would be required to reduce the coordination burden. Either measure would have adverse implications for potential users of the available spectrum:

- Increasing the frequency separation would reduce the amount of available spectrum in the upper band (depending on type of use), e.g. from 4 MHz to 3 MHz. This would further reduce the range of technologies that could be deployed in the band. In particular, it may

[32] It is yet to be demonstrated that filtering solutions can be implemented at the relevant O2 base sites (being dependent, amongst other things, on the physical configuration of the base station and the space available).

no longer be possible to implement CDMA technologies, as a 3 MHz block would not provide sufficient spectrum to accommodate three channels of 1.25 MHz.

- Imposing an additional power limit may prevent a new entrant operator from deploying wide area macro sites, limiting deployment options to lower power, micro or pico cell coverage. This would rule out use of spectrum for wide-area network applications.

The combination of these restrictions (lack of wide area coverage and sufficient spectrum for a maximum of two 1.25MHz channels) means that it is unlikely to be economically viable to use this band to deploy a national mobile network (e.g. based on CDMA2000 technology). The band could be used for providing data services in local hot spots, however such services are more commonly provided using technologies such as IEEE802.11 in unlicensed spectrum bands.

The results of this revised analysis only became available during the final stages of this project. As discussed below, these restrictions have significant implications for our assessments of demand, viability of potential uses and assignment options.

4.1.3 European harmonisation

Our understanding is that the 872-876 MHz and 917-921 MHz bands are not widely used for commercial services across Europe, as they are used by military services in some countries. ERC/DEC/(96) 04 designates the bands for digital land mobile (TETRA) systems in countries where this is required. The recent ECC Decision on wideband digital land mobile systems includes 872-876/917-921 MHz as a possible band for wideband PMR/PAMR systems, depending on market demand.

This spectrum is also a preferred band in Europe for tactical radio relays (TRR) and designated for defence systems in ERC Report 25 (the European Common Allocation Table).

ECC Decision (04)06 identifies this spectrum as a preferred band for digital land mobile PMR/PAMR systems based on the TETRA standard. It was envisaged that this band would be used for TETRA2, providing a higher data rate capability to the original TETRA standard. The United Kingdom has not implemented these Decisions and, for the purposes of this study, we have assumed that licences can be issued on a technology and service neutral basis.

4.1.4 International coordination

These bands are used in France for tactical military links. It is not expected that this will add significant constraints on the use of the bands in the United Kingdom, according to discussions with Ofcom. It is not clear whether MOU arrangements with France (and Ireland) are in place for these bands; these may need to be negotiated by Ofcom.

In Ireland, a recent ComReg consultation makes proposals for the 872-876/917-921 MHz bands to be made available for wideband mobile data services in line with ECC/DEC(04) 06. In principle, there could be scope for the creation of an all-Ireland licence, as has been discussed for the 410-415 & 420-425 MHz band (see Section 3.1.3).

4.2 Potential future uses

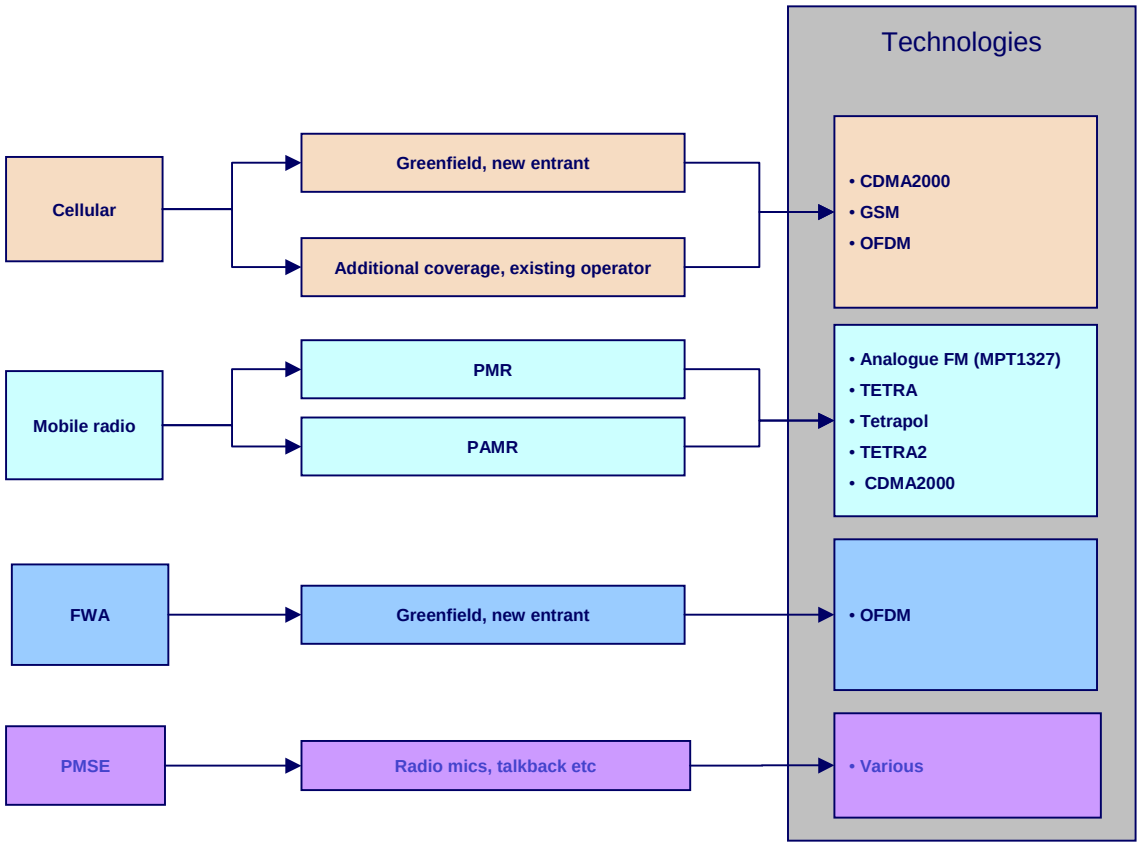
In principle, there are a wide range of candidate uses for spectrum in the 800 and 900 MHz bands, including most mobile and wireless broadband technologies. In practice, many of these candidate uses are ruled out, as they would require at least 2 x 5MHz.

Figure 5 illustrates the remaining candidate uses, once the limitation in spectrum availability is taken into account. The most likely use that we initially identified is deployment of a mobile network, e.g. using CDMA2000 technology. However, in light of Ofcom's revised findings that additional coordination restrictions will be required to prevent interference with GSM, it appears that wide-area CDMA2000 deployment will not be viable. Furthermore, the band is not attractive for GSM, as it falls outside the range of frequencies that can be used by existing GSM equipment and we understand from discussions with Ofcom and also from the mobile operators that it is unlikely to be technically feasible to develop a handset which is able to operate in this band and the main 900MHz allocation for GSM.

Further, although the band is potentially suitable for PMR/PAMR use, it is considered significantly less attractive than spectrum in the 410-430 MHz band, owing to the lack of available equipment and the higher network deployment costs for wide-area coverage.

One remaining licensed use would be for radio microphones for PMSE, e.g. as replacement spectrum if PMSE users are squeezed out of VHF Band III and/or the UHF frequencies. However, this is not a core-band for PMSE, so new equipment may be required. Alternatively, the spectrum could be used for licence exempt use, such as short-range devices. However, we have no evidence that such an allocation is required. Further, allowing licence exempt use could effectively sterilise the spectrum for some future licensed use, including a link-up with the GSM-R band, if this eventually become available.

Figure 5: Candidate uses for the 872-876 & 917-921 MHz band



4.3 Demand assessment

Market demand for this band appears limited. Principal interest in the band arose from its potential use for the deployment of a national mobile network using a technology such as CDMA2000. However, at the time of the interviews, we and the interviewees were unaware of Ofcom's revised assessment that additional coordination constraints on this spectrum will be required. Once this assessment is widely known, such interest may dissipate.

Other potential uses highlighted by interviewees were:

- PMR – industry generally indicated this band is less attractive than the 410-430MHz spectrum owing to the limited coverage and current lack of available equipment; and
- PMSE – this band could potentially be used as replacement spectrum for VHF or UHF bands (e.g. for radio microphones).

Our view, even before we learned of Ofcom's revised assessment, was that demand for this spectrum would be limited, perhaps being restricted to one or more potential mobile voice/data entrants. Existing UK mobile network operators are not interested in the spectrum, as it is not a harmonised band

for the deployment of GSM/W-CDMA technologies. Furthermore, our interviews with financial institutions indicated that they are unlikely to invest in a new start-up national mobile operator.

4.4 Viability and value of potential uses

Prior to becoming aware of the full nature of constraints resulting from the filtering requirement to protect O_2's base stations from harmful interference, we modelled two potential uses of the spectrum:

- deployment of a CDMA2000 mobile voice and data network
- deployment of a CDMA2000 mobile data only network.

We found that to construct a viable business case for both these types of use, it was necessary for the new operator to be extremely successful in winning market share from the existing MNOs. However, this finding was based on the assumption that the operator would be able to deploy a wide-area network using three CDMA2000 carriers enabling it to support voice and high-speed data services on its network.

The nature of the filtering constraints required to support O_2 would mean that it would only be possible to deploy two CDMA2000 carriers in the band, rather than three (which is what we have assumed for the purposes of developing our financial models) and that it would not be possible to use the spectrum from macro-cell coverage.[33] These restrictions would severely limit the coverage of the network to local hot spots as well as limiting the capacity available at each hot-spot. Given the difficulties of developing user terminals which can operate in this band and the existing GSM bands, the scope for roaming between this local network and the conventional GSM mobile networks appears limited. This may curtail subscriber interest in the services. Further, the availability of two carriers limits the number of subscribers that could be supported in any case. It is unlikely that any party could make a viable business case for a mobile voice and/or data network given these restraints.

4.5 Competitive implications

4.5.1 Structure of demand

In the event that an aspiring mobile operator was able to construct a business case for this band, it would presumably require all available

[33] Ofcom published a note on technical constraints associated with the 917-921 MHz band on its website: http://www.ofcom.org.uk/consult/condocs/sfrip/constraints/ on 24 February. It shows that filtering might not be required if transmit power were restricted to 32 dBm.

spectrum in this band. Demand would most likely be for a national network; our interviews found no evidence of regional demand.

PMSE demand is for use on a local basis with locations potentially varying over time. PMSE users would not require all the spectrum in the band, but granting larger blocks on a national basis would increase flexibility for a band manager.

4.5.2 Competition issues

We have not identified any market power concerns related to the assignment of this spectrum.

The main competition-related concern is the potential lack of demand for the spectrum. Indeed, in light of the revised coordination constraints, it is possible that there will be no demand for this spectrum at all. Any assignment procedure would need to be robust to low competition scenarios.

One possible bidder for the spectrum is O_2. If the spectrum was available sufficiently cheaply, O_2 might buy it simply to prevent exposure to future coordination risks and establish a right not to receive interference (which it could always subsequently relax by allowing limited use if it wished). If this were the only source of demand, Ofcom may consider it preferable not to licence the spectrum at all at this point, pending future market developments.

The spectrum could also be bought speculatively by an organisation hoping to profit from a windfall gain if some future use for the spectrum is identified (e.g. use with the adjacent GSM-R band). This may be considered undesirable to the extent that the windfall gain is accrued by a private party rather than the state. On the other hand, it is possible that a speculator could play a key role in identifying new uses, thereby facilitating more rapid deployment of the spectrum than if the state had held on to it pending changes in market circumstances.

4.6 Packaging of spectrum

In the SFRIP, Ofcom proposes to award a single UK-wide licence for all available spectrum. We concur that this is the most appropriate way to package the spectrum given the nature of possible demand. Our reasoning is summarised in Table 5.

We have also considered the possibility of allocating the spectrum on a licence exempt basis, with appropriate restrictions on use. However, we would caution against such a move without further study of demand. Allowing licence exempt use could effectively sterilise the spectrum for some future licensed use, including a link-up with the GSM-R band (if this eventually become available).

Table 5: Packaging options for the 872-876 & 917-921 MHz band

	Comments	Assessment
Regional licences	Could facilitate creation of all-Ireland licence No evidence of other regional-specific demand May create aggregation risks for national bidder Regional demand could be addressed in secondary market	✘
Nationwide licence	No evidence of demand for smaller configurations of frequency Demand expected to be national (except possibly Northern Ireland)	✓

4.7 Suitability of auctions

In the SFRIP, Ofcom proposes to assign this spectrum by auction. We concur than an auction will be the optimal assignment mechanism if there is a reasonable expectation of demand. An auction can produce a more efficient outcome than assignment by comparative selection, and may also be faster, more cost-effective to implement, more transparent and robust to legal challenge. Further, there are no reasons to suppose that an auction would disadvantage any likely users of this spectrum, based on our market assessment.

Nevertheless, given the uncertainty over demand for this spectrum, it is uncertain whether an auction is strictly necessary. Indeed, if there is no demand at all, resources used preparing an auction may be wasted. If there is only one bidder, the spectrum could simply be awarded directly without a contest. It may also be the case that if all likely demand is from parties that will not actually use the spectrum, Ofcom would prefer to withhold the spectrum from the market for the time being pending stronger evidence of real demand for its use.

One possible way forward is for Ofcom to undertake a formal 'demand evaluation' stage prior to making a decision on final design of an assignment mechanism. Potential users would be required to express interest in acquiring the spectrum and provide information about how they intend to use it. Only companies that participated in the demand evaluation would be allowed to proceed to an auction stage.

Ofcom could use this information to determine:

- whether the proposed uses of the spectrum were sufficiently valuable to justify assignment of the spectrum at this time (the threshold for 'proof' would presumably be set very low); and
- whether there was enough demand to justify holding an auction.

Bidders may submit an expression of interest but subsequently decline to make an offer for the spectrum, so the assessment of demand would not be certain. This weakness could be overcome by tying the expression of interest to a binding offer (backed by a deposit) to buy the spectrum at a fixed reserve price, if there are no other valid bids.

4.8 Auction / assignment options

A single block could be sold by either an ascending bid or sealed bid auction. A summary of our assessment of these options is provided in Table 6. We favour using a sealed bid for this spectrum, as this format is more robust to a low competition scenario. Specifically, a first price sealed bid is likely to be the best format for attracting entry and reducing the impact of bidder asymmetries.[34]

A first price sealed bid would be ideal if there are only two bidders. It could also be used if there is only one bidder, provided Ofcom did not disclose information about the number of participants. In this case, the bidder could be expected to bid a proportion of its value in excess of the reserve price, potentially realising greater revenues for the state.

In the event that there were more that two bidders, the efficiency of a sealed bid could potentially be improved by preceding it with an ascending bid phase (assuming that the bidders shared some common value).[35] During the ascending bid phase, the price would rise until there were just two bidders left. These bidders would then compete in a sealed bid auction, with a reserve price set as the high price reached in the ascending bid phase.

[34] There may be significant bidder asymmetries if O_2 participates.

[35] This is a so-called Anglo-Dutch hybrid auction. See Section 2.2.3 for further explanation.

Table 6: Auction format options for the 872-876 & 917-921 MHz band

	Comments	Assessment
Ascending bid auction	Slightly more complex to run than sealed bid Attractive to strong bidders, as pay no more than necessary to win Licence would sell at reserve price if no competition	✘
Sealed bid auction (second price)	Incentive for bidders to reveal their valuations Somewhat less advantageous to weak bidders than first price auction Low revenue if bidders are very asymmetric Licence would sell at reserve price if no competition	✘
Sealed bid auction (first price)	May raise higher revenues under low competition scenario (including a scenario where there is only one bidder but the number of bidders is not revealed until the auction is complete) May attract more bids from potential entrants if bidders are asymmetric Could be preceded by ascending bid stage if more than two bidders (Anglo-Dutch hybrid)	✓

4.9 Timing

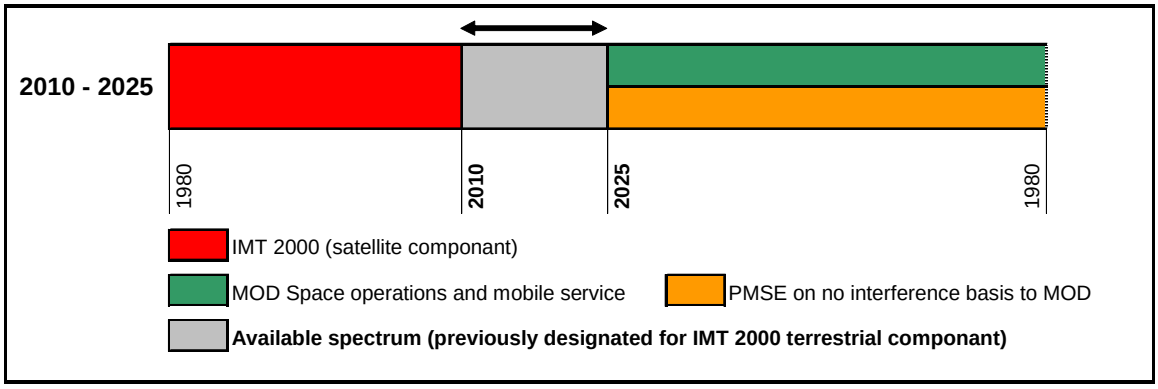
Given the apparent lack of market interest in this spectrum, there does not appear to be any need to rush to release it to the market. To the extent that Ofcom's resources for assigning spectrum are scarce, the other bands assessed in this study should take precedence. A key issue to clarify is whether there is any remaining interest in using the spectrum once the market is aware of the need for onerous coordination restrictions. Here, Ofcom will need to make clear exactly the nature of the obligations on a new entrant to resolve (and pay for) interference coordination with O_2. There may be a case for holding back the spectrum from the market if more concrete evidence of actual demand for its use cannot be identified.

5 The 2010-2025 MHz band

The spectrum consists of a contiguous 15MHz block, including guard bands at either end. It is available nationwide, unencumbered by any existing use.[36] The location of the spectrum and neighbouring uses are illustrated in Figure 6.

This spectrum is part of the set of core 3G bands identified by the World Administrative Radio Conference in 1992. It is currently designated as licence exempt for self-coordinating IMT 2000 systems, in accordance with ERC/DEC/(99) 25. However, the spectrum is not being used, as there have been no developments towards implementation of IMT-2000 TDD solutions capable of operating in a licence-exempt mode. In the SFRIP, Ofcom proposes "*to licence use in this band and award those licences through an auction*".

Figure 6: The 2010-2025 MHz band and adjacent spectrum



5.1 Available spectrum and constraints on its use

This is a significant block of spectrum that could, in principle, be used by many different technologies. There are some restrictions on use, resulting from interference coordination with neighbouring bands and EU harmonisation initiatives. The value of the spectrum may also be affected by decisions about the availability of spectrum in certain other bands, which could be used either as a substitute (for TDD technologies) or to create a duplex pairing for FDD technologies. We explore each of these points in the following subsections.

[36] The band was previously used for fixed links but these were cleared in preparation for the UK 3G auction. We understand from Ofcom that one 'troposcatter' link remains, operated by Stratos, but this is expected to be decommissioned in mid-2005.

5.1.1 Guard bands and coordination with neighbouring bands

As presently configured, only 14.2 MHz of spectrum (2010.5 to 2024.7 MHz) in this band is actually available for use, with the remaining frequencies (2010-2010.5 and 2024.7-2025 MHz) designated as guard bands. These guard bands were established as a result of CEPT compatibility studies undertaken alongside the development of the ERC decision on use of licence-exempt spectrum in this band. There may be scope for revising these guard bands in future, depending on the type of technology ultimately deployed in this spectrum. In particular, it is our understanding that the 1990-2010 MHz allocation is not being used by mobile satellite services, which suggests an unresolved question as to whether this guard band is necessary.

5.1.2 European harmonisation

ERC/DEC/(99)25 designates this band for use for licence-exempt UMTS TDD systems. We understand that ECC PT1 is examining this issue at present and it is likely that the licence-exempt requirement will be removed, but that the UMTS TDD designation may remain. Meanwhile, other western European regulators, such as RegTP in Germany, have issued public consultations on use of the 2010-2025 MHz band.[37] Thus, greater clarity on the European Framework for this band is expected to emerge in 2005.

In the SFRIP, Ofcom indicates that its preference is to issue the spectrum on a technology-neutral basis, which would make the spectrum available for technologies other than UTRA TDD. For the purposes of this study, we presume that Ofcom can meet its European obligations by licensing any use that is compatible with the existing TDD channel plan. However, we understand that Ofcom has not yet had legal clarification that it can proceed on this basis. Further, even this more relaxed restriction may prevent some technologies from using the band. Unless this issue is resolved in advance of assignment, it would obviously be a source of uncertainty for bidders.

The fact that the spectrum is vacant and potentially available across Europe makes it attractive to manufacturers. Thus, potential users may be able to benefit from economies of scale if they use equipment that is used in multiple European countries. The value of the spectrum in the United Kingdom may therefore be enhanced if other European countries indicate that they also plan to take a similarly liberal approach to determining its use.

[37] Results of these consultations were not been available at the time of producing this report. In Germany, one of the TDD channels in the 2010-2025 MHz band is already licensed to E-Plus.

5.1.3 International coordination requirements

International coordination requirements are unlikely to impose significant constraints on the use of this spectrum. MOU arrangements are in place between the United Kingdom and France and Ireland for the co-ordination of UMTS TDD systems in border areas.

5.1.4 Relationship with other bands

Although this spectrum is currently designated for TDD use, it could also be used for FDD technologies, which require paired spectrum. There are three candidate bands for pairing with this spectrum:

- existing TDD assignments (1900-1920 MHz), which are already assigned to four of the five UK mobile network operators;
- the 2290-2302 and 2302-2310 MHz bands, the first of which is one of the bands reviewed in this study; and
- the 2500-2690 MHz band, which is designated in Europe for 3G expansion.

Amongst these, pairing with the 2500-2690 MHz band appears to be the most attractive option, as the spectrum is vacant and available across Europe. As we discuss in Section 6, the 2290-2302 MHz band is UK-specific and spectrum at 2302-2010 MHz is not currently available. We understand that there have been discussions within CEPT and 3GPP in relation to pairing the 2010-2025 MHz band with other IMT-2000 bands, to create additional 3G FDD capacity. A study item within 3GPP is considering the feasibility of pairing with the 3G expansion band.

Although these other bands are complements to the 2010-2025 band for FDD technologies, they are potential substitutes for TDD technologies. This has significant implications for the structure of potential demands for this spectrum, which we review in Section 5.5.

5.2 Potential future uses

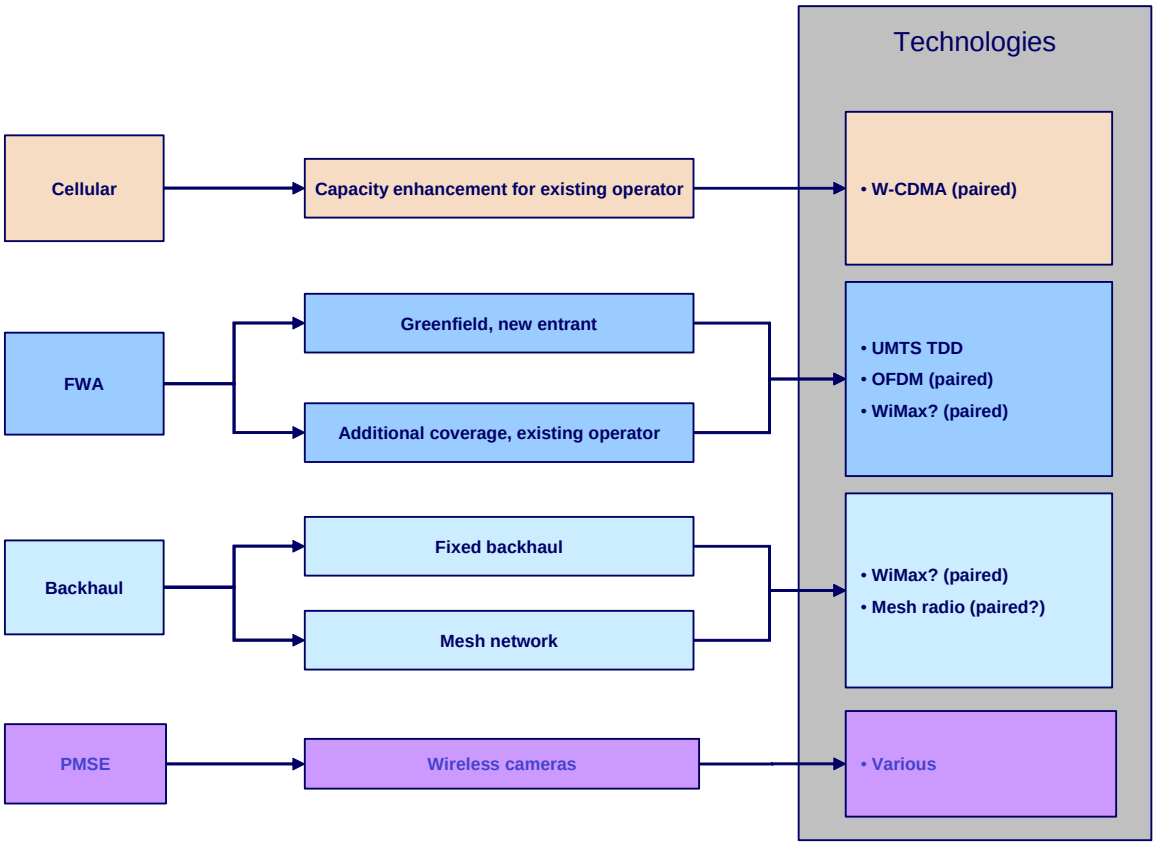
This band could be used for a wide variety of services and technologies, as illustrated in Figure 7. Candidate services include:

- mobile data;
- fixed wireless broadband; and
- vision carriers for programme makers

As well as being suitable for 3G use based on IMT-2000 technologies, the band is potentially suitable for many other fixed and mobile uses such as WiMAX (IEEE 802.16) and Mobile Broadband (IEEE 802.20), provided manufacturers are willing to develop equipment for this band. There is no reason why future use of this band should be restricted to IMT-2000 technologies. Specific technologies that could be used include the TDD systems offered by IP Wireless and Arraycomm; and FDD systems, such as

Flarion and WCDMA. Our understanding is that TDD technologies could probably be deployed immediately in this band. The FDD technologies would require paired spectrum and the systems would need to be adapted to these bands. Note that use of the spectrum by some these technologies may be constrained if the spectrum mask and guard band arrangements specified under ERC/DEC/(99)25 are maintained.

Figure 7: Candidate uses for the 2010-2025 MHz and 2290-2302 MHz



5.3 Demand assessment

Our interviews found strong interest in acquiring this spectrum from three categories of user:

- existing MNOs for mobile network capacity enhancement (pairing with spectrum in another band);
- fixed network operators and new entrants (ISPs) for providing fixed wireless access services; and
- the PMSE community for an additional 10MHz vision carriers (to complement the JFMG's 2025-2030 MHz holding)

The interviews also highlighted a number of key issues with implications for packaging and assignment of the spectrum:

- *Technology neutrality*. A wide variety of technologies are being considered by potential users of this spectrum, especially in relation to wireless broadband networks. Technology neutrality may therefore be critical in maximising interest from bidders and their equipment vendors in this spectrum.
- *Configuration of spectrum*. Notwithstanding the variety of technologies that could be deployed, all demand identified, apart from PMSE, was for multiples of 5MHz channels, compatible with the existing TDD channel plan. The JFMG would require 5MHz or 15MHz of spectrum, to combine with the JFMG's existing 5MHz holding. Alternatively PMSE equipment users (e.g. existing broadcasters) may seek 10MHz of contiguous spectrum, which would be compatible with acquiring two adjacent 5MHz blocks. No interviewees expressed a demand for regional licences rather than national licences.
- *Links with other bands.* Some bidders interested in deploying FDD technologies expressed a desire that the spectrum could be sold in conjunction with either the 2290-2302 MHz band or the 3G expansion band. The MNOs were particularly keen that this spectrum be assigned alongside the 3G expansion band.
- *Finance*. Although some ISPs expressed strong interest in the spectrum, it may be questioned whether this will translate into real bids for the spectrum. Our interviews with the financial community indicated they are currently reluctant to fund new start-up wireless broadband providers until the model is more proven.

5.4 Viability and value of potential uses

We assessed the financial viability of three alternative uses of the band:

- *Additional 3G mobile capacity*. MNOs are likely to have significant value for this spectrum, when combined with other IMT-2000 TDD spectrum (e.g. existing TDD spectrum holdings or new spectrum from the 3G expansion band). However, the importance of this particular spectrum to them is diminished by the fact that large amounts of alternative substitute spectrum (including pre-paired FDD spectrum) will become available when Ofcom releases the 3G expansion band.
- *Fixed wireless access service*. It is possible to construct viable business cases for various combinations of spectrum use with TDD or FDD technologies, although in many cases the assumptions required in respect of winning market share from other broadband service providers and the revenues generated from each subscriber would have to be very optimistic. Business cases are generally stronger/more viable with larger spectrum endowments.
- *Vision carriers for PMSE*. This use is certainly viable but the value of the spectrum may be small in comparison with alternatives.

5.5 Competitive implications

5.5.1 Structure of demand

There is the potential for high demand for this spectrum from multiple parties using a variety of technologies. Introducing service and technology neutrality should help to maximise interest in the band and ensure efficient assignment. The difficult financing environment for new entrants in this sector means that high interest will not necessarily translate into high demand.

Demand from some parties could be as little as one 5MHz carrier, while others may demand all 15MHz. Thus, the assignment mechanisms should allow bidders to express their demand for one, two or three blocks of 5MHz. This means that there may be more than one successful bidder, so arrangements will be required for them to coordinate mutual interference.

The 2290-2302 MHz band and 3G expansion band are potential complements and/or substitutes for this spectrum for several of the proposed uses. Therefore, the relative timing and assignment procedures adopted for these bands could have a material impact on the business cases and bid strategies of potential users. Specifically, bidders are potentially exposed to aggregation and/or substitution risks which, if not addressed in the assignment design, could deter bidders and result in an inefficient outcome. Later in this section and in the section on the 2290-2302 MHz band, we explore possible ways to link these auctions to mitigate such risks, while keeping in mind the downside risk of any delay in assignment this might cause.

5.5.2 Competition issues

We do not foresee any market power concerns associated with assigning this spectrum, notwithstanding the potential participation of MNOs. Any use of the band for wireless broadband would clearly be pro-competitive, as such a service would be additional to fixed offerings. Purchase of the spectrum by existing MNOs does not raise any competition concerns as:

- no MNO currently has significant market power according to Ofcom's most recent Market Review, so there is no objective justification for restricting the quantity of spectrum any particular MNO may purchase; and
- even if a single MNO purchased all the available spectrum in this band, it is difficult to see how this could have a material effect on competition, much less lead to the emergence of a dominant position.

It is possible that an MNO may buy the spectrum for option value rather than for immediate use. However, this is a legitimate business decision, and represents an efficient use of the spectrum provided that the MNO's option value exceeds the willingness to pay of other potential users.

Ofcom also asked us to consider whether the possibility of a large programme maker (instead of band manager) buying this spectrum could raise any competition concerns. We note that the spectrum available in this band would represent only a small proportion of spectrum managed by JFMG for PMSE users that is suitable for vision carriers. Therefore, we do not believe that such a transaction should cause any concerns.

5.6 Packaging of spectrum

In the SFRIP, Ofcom proposes creating multiple licences split by frequency (e.g. three 5MHz licences or one 5MHz and one 10MHz licences). We concur with Ofcom's view that creating three 5MHz blocks would maximise flexibility for potential users to acquire the optimal amount of spectrum for their particular use. Creating blocks of 5MHz that can be amalgamated if necessary is consistent with all likely uses of the spectrum and is compatible with the European-wide TDD channel plan. Our interviews indicated broad support for this approach from industry.

We recommend assigning three 5MHz blocks: 2010-2015 MHz, 2015-2020 MHz and 2020-2025 MHz, subject to clarification of the constraints imposed by the guard bands specified by ERC/DEC/(99)25. These guard bands mean that some spectrum in the first and third blocks may not be available for use. However, it may be possible for Ofcom to replace the guard bands with more general obligations on interference management, subject possibly to agreement within Europe on revisions to the ERC decision. If allowed, revisions could also be achieved by negotiation between neighbouring users in the secondary market. If there are no changes to the guard bands, some alternative configuration may be optimal in order to maximise the scope for different TDD and FDD technologies to use this spectrum.

We do not see any compelling reason for geographically sub-dividing this spectrum. There was no request for regional licences from any of our interviewees. Additionally, the secondary market will be able to subsequently reconfigure the spectrum to meet changing needs should these arise.

One further packaging option would be to pair the 5MHz blocks with spectrum in another band. This could be attractive for some potential users of FDD systems – for example, the MNOs advocated a formal pairing with the 3G expansion band. However, in our view, it would be better to let the market decide on any pairing, whether through the primary assignment mechanism or in the secondary market. Pairing the spectrum in advance of assignment would discriminate against TDD use; further, there are several options for pairing this spectrum, and ideally the market rather than Ofcom should decide which one is optimal.

Table 7: Assessment of packaging options for 2010-2025 MHz band

	Comments	Assessment
Regional licences	No evidence of regional demand Potential aggregation risks for national bidders Regional demand could be addressed in secondary market	✘
One national licence	Demand expected to be national Risk of inefficient outcome as combined business case of 2-3 winners may be greater than single winner	✘
Three blocks of 5MHz nationwide	All feasible uses need 5MHz carriers (paired or unpaired) or 10MHz contiguous. 5MHz is minimum amount needed for viable business Bidders needing more than 5MHz could aggregate blocks	✓
One block of 5MHz and one block of 10MHz	Less flexible for bidders than having three 5MHz blocks	✘
Pair blocks with another band	This would discriminate against TDD use The spectrum could be paired with several bands; better to let the market decide which one (if any) is optimal	✘

5.7 Suitability of auctions

In the SFRIP, Ofcom proposes to assign this spectrum by auction. We concur than an auction is the optimal assignment mechanism, for the following reasons:

- There is a high likelihood that there will be excess demand for the spectrum. Therefore, Ofcom requires a mechanism that can choose between competing bidders. An auction can produce a more efficient outcome than assignment by comparative selection, and may also be faster, more cost-effective to implement, more transparent and robust to legal challenge.
- The potential bidders will have substantial investment plans linked to any purchase of spectrum. Participation costs should be small relative to the value of the spectrum.
- Individual lots and associated spectrum rights can be clearly defined. However, owing to differences in guard band arrangements and benefits from having contiguous spectrum, the value of the three lots

may vary. Further, there are potential complex interactions with at least two other spectrum bands (the 2290-2302 MHz and 3G expansion bands). Auctions can be designed to help bidders manage trade-offs in value between different combinations of blocks both within and across bands.

5.8 Auction / assignment options

5.8.1 Linkages with other bands

The first step in reviewing assignment options is to determine whether this spectrum should be auctioned alone or linked to the auctions of one or both of the 2290-2302 MHz and 3G expansion bands. In the SFRIP, Ofcom considers a link with the 2290-2302 MHz band: "*It does not envisage a single auction for the bands but it may be possible to hold two auctions at the same time perhaps allowing bidders to make bids in one auction conditional upon a certain outcome in the other auction*." We note that this does not foreclose the possibility of a single auction, and that Ofcom has invited comments from the industry on how the auctions might be linked.

In our view, there is a strong case for combining the auctions of spectrum lots in the 2010-2025 and 2290-2302 MHz bands, providing the lots themselves can be purchased either separately *or* combined:

- Spectrum in both bands is available now, so combining them would not delay assignment to users (subject to early resolution of any legal issues concerning interpretation of EU harmonisation in the 2010-2025 MHz band).
- Spectrum in the 2290-2302 MHz band may be either a substitute or a complement for spectrum in the 2010-2015 MHz band, depending on the business case of particular bidders. A single auction could be designed to help bidders manage the various substitution and aggregation risks, thereby maximising the likelihood of efficient assignment. With separate auctions, the scope for minimising such risks may be diminished.
- There may be cost savings for Ofcom from combining the sale of these two bands in a single auction.
- Given the small number of spectrum lots involved, combining the two auctions should not significantly increase complexity for the auctioneer or for bidders.

The case for combining this auction with spectrum in the 3G expansion band is weaker. This is not because the synergies between the bands are any less important than those with the 2290-2302 MHz band. Rather, it is simply because the 3G expansion band spectrum is not yet ready for release. Thus, any attempt to link the auctions may require a significant delay in assignment of this spectrum. It is likely that the costs of delay would outweigh any benefits, for the following reasons:

- The delay would be most detrimental to new entrant bidders planning products that would compete with fixed broadband networks and 3G data networks. The UK broadband market is still at an early stage of development but is maturing rapidly; the later the entry, the less chance of success, as the entrant must compete for customers switching from other providers rather than for new joiners to the market. Our analysis suggests that FWA business cases are already marginal (and obtaining finance is difficult); further delay could undermine the case for entry completely, leading to a less competitive auction, and potentially less competitive outcomes in downstream service markets.
- If this spectrum (or the 2290-2302 MHz band) led to innovative broadband or mobile data services, this could generate significant welfare benefits for consumers that would be delayed. Estimates for other related services suggest that such losses can be substantial.[38]
- Delay would favour parties that do not need to use the spectrum immediately and/or want to pair it with the 3G expansion band. The obvious beneficiaries are the MNOs. Our market assessment suggests that the MNOs will probably be the strongest bidders in an auction anyway. They are also in a stronger position than entrants to manage any aggregation risks across bands. Therefore, it is not obvious that decoupling this band from the 3G expansion band would create significant inefficiency.

5.8.2 Auction design

Our favoured option is to combine this auction with that of the 2290-2302 MHz band. We assess the design options for a combined auction in Section 6.8.3, after our assessment of the 2290-2302 MHz band. Here, we review Ofcom's options if it decided to auction this band separately.

In this case, Ofcom would be faced with a simple auction of three lots, with no restrictions on the number of lots that each bidder could win. Either a sealed bid or SMRA format could be used:

- The sealed bid would need to have a combinatorial element, to allow bidders to express their relative preferences for different combinations. With just three lots, there are only seven possible combinations, so this would be simple to implement.
- With an SMRA, bidders could both switch demand between lots and decrease total demand over multiple rounds in response to rising prices and changes in relative prices. This flexibility should be sufficient to

[38] See Section 2.2.4 for a general discussion of the costs of this type of delay.

allow bidders to manage substitution and aggregation risks, so a combinatorial element to bidding would not be necessary.

On balance, we would favour using an SMRA if this band were auctioned alone. This is because, from an efficiency perspective, SMRAs are superior to sealed bids in common value settings, provided that there are no competition concerns such as few bidders or highly asymmetric bidders. Our market assessment indicated that low competition is unlikely to be a concern for this specific band.

5.9 Timing

We share Ofcom's view, stated in the SFRIP, that this spectrum should be auctioned as soon as practically possible. Although some interviewees would like this spectrum to be assigned with the 3G expansion bands, we do not recommend this because the resulting delay could undermine the business case for new wireless broadband providers and may delay consumer benefits from any innovative new products that might result.

The timing of the assignment of this spectrum relative to that of the 2290-2302 MHz band could affect the bidding behaviour of potential users. Our view is that it would be best to combine the auctions. However, in the event that Ofcom decided to auction the bands separately, it is important that this band be auctioned first. This is because for TDD applications, the 2290-2302 MHz band is a much inferior substitute. Thus, substitution risks should be mitigated if these bidders can first bid for their preferred spectrum and then only switch demand to the alternative if this becomes prohibitively expensive.

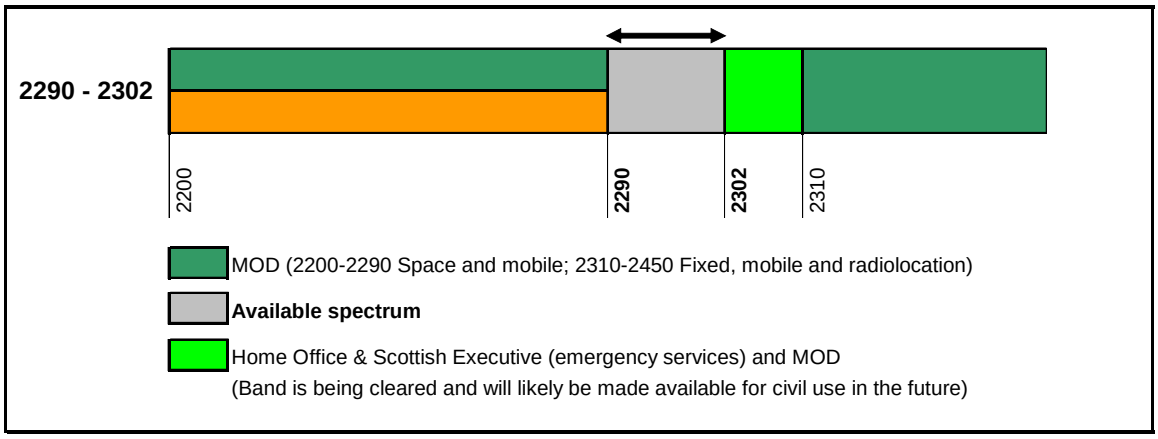
Some potential bidders for this band envisage deploying technologies that could be considered as competing with 3G. Ofcom is currently reviewing its policy on liberalisation of spectrum for provision of 3G-type services. Its position on this will need to be clarified in advance of the auction, as it is a source of uncertainty for bidders, especially entrants. As policy currently stands, it is possible that 3G services might be supplied even prior to 2007 using this spectrum band, as this is currently an unallocated band and so no change of use is required. However, Ofcom would need to confirm this interpretation.[39]

[39] The 2003 consultation on Spectrum Trading says that Ofcom would not expect to allow other bands not presently designated for 3G to change their use to offer 3G services until 2007. However, no change of use is required in this band and it is anyway designated for 3G use by ERC/DEC/(99)25.

6 The 2290-2302 MHz band

The available spectrum consists of a contiguous 12MHz block, which forms the lower part (2290-2302 MHz) of the 2290-2310 MHz band. Most of it has been recently released by the MoD and is available nationwide, unencumbered by any existing use. The remaining 8MHz in this band is currently used by emergency services but is being cleared and will potentially be available for release to the market at an unspecified date. The location of the spectrum and neighbouring uses are illustrated in Figure 8.

Figure 8: The 2290-2302 MHz band and adjacent spectrum



6.1 Available spectrum and constraints on its use

The available frequencies have similar characteristics to the 2010-2025 MHz band, reviewed in the previous section. However, the amount of spectrum available is smaller (12MHz vs 15MHz) and it is UK-specific. These factors make it less attractive than the 2010-2025 MHz band for potential users, although the first problem could be removed if spectrum in the 2302-2310 MHz band is released. Below, we review these and other constraints on the use of this spectrum.

6.1.1 Availability of this spectrum and the adjoining 2302-2310 MHz band

Most mobile and FWA technologies that could use this spectrum require 5MHz carriers. As 12MHz spectrum is available, this means there is room for only two carriers. Most technologies would not be able to make use of the extra 2MHz available.

Up to two additional carriers could be accommodated if this spectrum was linked with the 2302-2310 MHz band. This spectrum is currently used by the emergency services. Although the band is being cleared, this is not a process that can easily be hastened, owing to safety of life implications. Ofcom has said that it will only release the spectrum when this process is

concluded. In the absence of any firm date, this will remain a source of uncertainty for bidders.

6.1.2 Absence of European harmonisation

The band is not harmonised across the EU and is unlikely to become widely available across other European countries in the foreseeable future. At the international level, the band is allocated to fixed, mobile (except aeronautical) and space research (below 2300 MHz) and fixed and mobile (above 2300 MHz). Our understanding is that the band is variously used in Europe for fixed links, outside broadcast (vision links), space research and military services.

There are no ERC Decisions that harmonise use of this band for a particular system or service. If Ofcom decides to make this band available on a service and technology-neutral basis, it is likely that the United Kingdom would be the first country to allow use of this spectrum by mobile and/or wireless broadband services.

6.1.3 Interference-coordination requirements

Future uses of the band will be subject to a number of coordination constraints related to uses in neighbouring bands and countries. However, none of these appear to place any significant constraints on usage:

- The neighbouring UK allocations include PMSE (digital point-to-point video links and portable video links, based on DVB-T technology) and the emergency services. As the latter are being moved from their band, this will ease coordination constraints.
- Our understanding is that there are no international co-ordination agreements in place affecting use of these bands. Should Ofcom licence this band for mobile services, negotiations would need to be commenced with the French and Irish regulators in order to agree conditions on which UK mobile systems can be operated in coastal areas to avoid mutual interference.
- The band above 2300MHz has a secondary allocation to amateur use and radiolocation. In ERC Recommendation 62-02 and the Common European Allocation Table, the band 2300-2400 MHz is foreseen for use by airborne telemetry. The recommended tuning range for such systems is from 2300-2400 MHz; however the lower portion (2300-2330 MHz) is considered as the 'core band'. Our understanding from Ofcom is that airborne telemetry use of the band in other parts of Europe does not place constraints on usage of the band in the United Kingdom.

6.1.4 Linkages with other bands

Spectrum in this band could be linked with other bands to facilitate FDD systems. Candidate bands include 2010-2025 MHz and 1790-1798 MHz.

The latter is currently paired with 2302-2310 MHz, but Ofcom has said that it does not intend to maintain this linkage once the emergency services have vacated these bands. In principle, the 2290-2302 MHz band could also be paired with the 3G expansion plan, although this is most unlikely, given the UK-specific nature of this band.

This band is also a potential substitute to the 2010-2025 MHz and 3G expansion bands for TDD technologies.

The presence of these linkages between bands needs to be taken into account in selection of the assignment process, in order to ensure bidders do not face undue aggregation or substitution risks across bands.

6.2 Potential future uses

The potential uses of this band are the same as those for the 2010-2025 MHz band (see Section 5.2), as the nature of the frequencies available are similar. However, because availability of this band is UK-specific, it is less attractive for services where there are significant economies of scale from deploying common equipment across countries. This is of greatest importance for mobile communications services and to a lesser degree also for fixed wireless networks.

6.3 Demand assessment

Our interviews revealed much less interest in this band than for the 2010-2025 MHz band. Two types of possible use were identified:

- provision of wireless broadband services by fixed network operators and ISPs considering deploying a wireless broadband network – this band could be used for TDD technologies or used in combination with the 2010-2025 MHz band for FDD technologies;
- a 10MHz vision carrier for the PMSE community, as this spectrum is adjacent to their existing holdings.

There was no interest from MNOs, owing to the UK-specific availability of the band. This same factor also deterred many potential FWA bidders, who expressed concern about the cost and availability of equipment.

The interviews also highlighted a number of key issues with implications for packaging and assignment of the spectrum:

- *Configuration of spectrum*. Most possible technologies envisaged for this band would require 5MHz blocks, while PMSE requires a single 10MHz block (equivalent to two carriers). Only one specific technology (Flarion) was identified that could utilise the full 12 MHz available (e.g. in two 6MHz blocks), but it would also work with 5MHz blocks. There was no interest in allocation of spectrum on a regional basis.
- *Linkages with the 2290-2302 MHz band*. For FWA operators, the spectrum is either an inferior substitute for the 2010-2025 MHz band (for TDD technologies) or a complement when paired (for FDD technologies).

6.4 Viability and value of potential uses

We modelled the financial viability of the two alternative uses for which we identified possible demand:

- *FWA services*. It is possible to construct a business case that places a positive value on the spectrum, either for TDD use or for FDD, paired with the 2010-2025 MHz band. However, the assumptions required for a positive value are bullish in respect of winning market share from other broadband service providers and the revenues generated from each subscriber. Business cases are generally stronger/more viable with larger spectrum endowments.
- *Vision carrier for PMSE*. The value of this spectrum to the PMSE community appears modest (relative to an optimistic business case for FWA) but certainly positive.

6.5 Competitive implications

Competition for the 2290-2302 MHz band would appear more limited than the 2010-2025 MHz band owing to its UK-specific nature. Although the problem of weak competition would appear more limited than the 872-876/917-921 MHz band, it would be prudent to ensure that any auction process was robust to the possibility of limited competition for this spectrum.

Ofcom also asked us to consider whether the possibility of a large programme maker (instead of band manager) buying this spectrum could raise any competition concerns. We note that the spectrum available in this band, as with the 2010-2025 MHz band, would represent only a small proportion of spectrum managed by JFMG for PMSE users that is suitable for vision carriers. Therefore, we do not believe that such a transaction should cause any concerns.

6.6 Packaging of spectrum

In the SFRIP, Ofcom proposes either licensing this spectrum as a single block or splitting it by frequency. We have considered a variety of options for splitting the spectrum, as illustrated in Table 8. In our view, the best option is to create two blocks of 5MHz that can be amalgamated if necessary by bidders. This maximises the ranges of technologies that can use the spectrum. Although there are technologies that could use the remaining 2MHz of spectrum in combination with the 5MHz blocks, we are concerned that including this spectrum now may sterilise use of remaining spectrum at 2302-2310 MHz for those technologies that require 5MHz blocks.

We recommend assigning two 5MHz blocks: 2290-2295 MHz and 2295-2300 MHz. The remaining 2MHz of spectrum could be held back for assignment with the 2302-2310 MHz band. This would facilitate the assignment of two 5MHz carriers in that band, which would expand the range and viability of potential uses.

We do not see any particular reason for geographically sub-dividing this spectrum. There were no requests from any of our interviewees for this. Further, any such demand in the future could be resolved through trading and reconfiguration in the secondary market.

We also considered two further packaging options:

- Holding back the spectrum until the 2302-2310 MHz band was ready for assignment, so that four 5MHz carriers could be created. We rejected this because it would unduly delay assignment of available spectrum for little obvious benefit. There is no reason why bidders should require certainty about the availability of 2300/2302-2310 MHz spectrum before bidding for 2290-2300/2302 MHz spectrum.
- The possibility of pairing the 5MHz blocks with spectrum in the 2010-2025 band. This was rejected, for the reasons explained in Section 5.6.

Table 8: Packaging options for the 2290-2302 MHz band

	Comments	Assessment
Regional licences	No evidence of regional demand; could anyway be addressed in secondary market May create aggregation risks for national bidder	✘
One block of 10MHz or 12MHz	Most viable uses likely to want two blocks of 5MHz Could prohibit viable use requiring just 5MHz (e.g. if this was paired with 2010-2025 MHz band)	✘
Two blocks of 6MHz, nationwide	Makes use of all available spectrum, but extra value of additional 1MHz per carrier is questionable, as most available technologies could not use this Could impede creation of third and fourth carriers when 2302-2310 MHz is eventually released	✘
Two blocks 5MHz & one block 2MHz	2MHz unlikely to be used other than as a guard band Assignment of 2MHz now may complicate future use in conjunction with 2302-2310 MHz band	✘
Two blocks of 5MHz, nationwide	All feasible uses can use combinations of 5MHz carriers (paired or unpaired) 2MHz of spectrum held back for later assignment with 2302-2310 MHz band	✓

6.7 Suitability of auctions

In the SFRIP, Ofcom proposes to assign this spectrum by auction. We concur than an auction is the optimal assignment mechanism, for the following reasons:

- It is likely that there will be excess demand for the spectrum at a zero price. Therefore, Ofcom requires some mechanism that can choose between competing bidders. An auction can produce a more efficient outcome than assignment by comparative selection or by choking off demand using AIP. It may also be faster, more cost-effective to implement, more transparent and robust to legal challenge.
- The potential bidders may have substantial investment plans linked to any purchase of spectrum. Participation costs in an auction should be small relative to the value of the spectrum.
- Individual lots and associated spectrum rights can be clearly defined. There are potential complex interactions with other spectrum bands, in particular the 2010-2025 MHz band. Auctions can be designed to help bidders manage trade-offs in value between different combinations of blocks both within and across bands.

6.8 Auction / assignment options

6.8.1 Linkages with the 2010-2025 MHz band

In Section 5.8.1, we assessed the case for linking an auction of spectrum at 2010-2025 MHz with spectrum in this band. We concluded that there was a strong case for assigning them in a single auction. Our reasoning is given in that subsection.

6.8.2 Design options for a stand alone auction

Our favoured option is to combine this auction with that of the 2010-2025 MHz band. Here, we review Ofcom's options if it decided to auction this band separately.

In this case, Ofcom would be faced with a simple auction of two lots, with no restrictions on the number of lots that each bidder could win. Either a sealed bid or SMRA format could be used:

- The sealed bid would need to have a combinatorial element, to allow bidders to express their relative preferences for different combinations. With just two lots, there are only three possible combinations, so this would be very simple.
- With an SMRA, bidders could both switch demand between lots and decrease total demand over multiple rounds in response to rising prices and changes in relative prices. This flexibility should be sufficient to allow bidders to manage substitution and aggregation risks, so a combinatorial element to bidding would not be necessary.

On balance, we would favour using a sealed bid combinatorial auction. Although SMRAs are normally considered to have superior efficiency properties to sealed bids in common value settings, this may not be true if there is low competition. Our market assessment suggests that low competition is a risk for assignment of this specific band.

6.8.3 Design options for a combined auction of the 2010-2025 MHz and 2290-2302 MHz spectrum bands

The purpose of combining the auction of these two bands is to allow bidders to better manage both aggregation and substitution risks across the bands. Our market assessment indicates the possibility of there being a variety of bidders with different and conflicting demand profiles across the five available blocks. This is the type of situation in which combinatorial bidding can be used to mitigate problems with simpler sealed bid or ascending bid auction formats.[40]

Table 9 summarises our assessment of options for a combined auction format. We have rejected using either a simple sealed bid or ascending bid auction format, because these would not mitigate risks for bidders:

- Simple sealed bids are inappropriate for auctioning multiple lots if they are substitutes or if the case for bidding for one lot is contingent on also winning another. Bidders simply submitting individual bids on lots have no capacity to express preferences between or across lots.
- An SMRA would remove substitution risks, as bidders would be able to switch demand between blocks. However, they would still be exposed to aggregation risks, as they must bid for a combination of blocks over successive rounds, uncertain whether they can actually win them all. This might potentially disadvantage technologies requiring pairing relative to those that do not require pairing.[41]

[40] See Section 2.2.3 for further explanation of combinatorial auctions.

[41] A bidder seeking paired spectrum would be particularly exposed to the risk of being 'stranded' with unwanted licences in the 2290-2300 MHz band. This is because, given the likely high levels of demand and value associated with the 2010-2025 MHz lots, the contest for these lots within the auction may continue long after competition for the 2290-2300 MHz lots is resolved. Introducing specific activity rules could help to ease these risks but would not eliminate them. A good example of this phenomenon is provided by the 2001 Canadian PCS auction. Critical lots in urban areas essential to entrants trying to build reasonable coverage areas were subject to a disproportionate amount of competition. Once incumbents had won these critical lots, demand for remaining lots dropped off. There were very large disparities in prices per pop across regions, with high prices in the critical regions despite overall revenues being modest relative to other comparably competitive auctions at the time.

Table 9: Assignment options for a combined auction of the 2010-2025 MHz and 2290-2302 MHz spectrum bands

	Comments	Assessment
Sealed bid	Robust to low competition scenario Exposes bidders to aggregation and substitution risks across blocks	✘
SMRA	Eases common value / winner's curse problem Less robust to low competition scenario than sealed bid Exposes bidders to aggregation risks, especially risk of stranded licence(s)	✘
Sealed bid combinatorial auction	Simple to implement with just five blocks Minimises aggregation risks across blocks Exposes bidders to common value / winner's curse problem	✓?
Ascending bid combinatorial	Mitigates aggregation (stranded licence) risks Eases common value / winner's curse problem More complex to implement than sealed bid	✘?

Allowing combinatorial bidding in either a sealed bid or ascending bid setting would mitigate these risks. By allowing bidders to submit a menu of bids, they would be able to express their relative preferences both between and across the lots. With five lots, the maximum number of combinations would be 31, which is a manageable number. It may be possible to reduce this number by ruling out some specific combinations; also, it is possible to restrict the total number of combinatorial bids that each bidder is allowed to submit.

The simplest approach would be to use a sealed bid combinatorial auction. Auction formats of this type have been used successfully to allocate radio spectrum in Norway and Nigeria, with (as in this case) up to five lots per auction. A software algorithm is required to determine the optimal configuration of bids that maximises value across all bids and lots.[42] However, given that most bidders would typically submit only a fraction of

[42] For example, DotEcon developed an auction algorithm for sealed bid combinatorial auctions of five lots which was used in the Nigerian FWA auction in 2002. This used a dynamic programming algorithm to determine the optimal allocation. Brute force search methods are infeasible on such optimisation problems.

the total number of bids available, it is highly likely that the results could also be interpreted manually.

In a combinatorial SMRA, bidders submit revised menus of bids over successive rounds, with prices increasing until supply matches demand. The same software algorithm as for a sealed bid is used to determine high bids at the end of each round. This format offers superior efficiency advantages over a sealed bid in a common value setting. However, it is more complex to implement and requires more active bidder participation (e.g. in terms of time and familiarisation with the process).

On balance, we do not think that the possible efficiency advantages of an SMRA over a sealed bid are sufficient to justify the additional complexity in this case. Therefore, we recommend running a sealed bid combinatorial auction.

6.9 Timing

We share Ofcom's view, stated in the SFRIP, that this spectrum should be auctioned as soon as practically possible. The timing of the assignment of this spectrum relative to that of the 2010-2025 MHz band could affect the bidding behaviour of potential users. Our view is that it would be best to combine the auctions. However, in the event that Ofcom decided to auction the bands separately, this band should ideally be auctioned after the 2010-2025 MHz band.[43] This is because for TDD applications, the 2010-2025 MHz band is a superior substitute. Thus, substitution risks should be mitigated if these bidders can first bid for their preferred spectrum and then only switch demand to this band if this becomes prohibitively expensive.

Potential bidders for this band envisage deploying technologies that could be considered as competing with 3G. Ofcom is currently reviewing its policy on liberalisation of spectrum for provision of 3G-type services. As discussed in Section 5.9 in relation to the 2010-2025 MHz band, its position on this will need to be clarified in advance of the auction, as it is a source of uncertainty for bidders, especially entrants.

[43] This conclusion may not hold if Ofcom anticipated that there could be problems resolving legal issues concerning interpretation of EU harmonisation in the 2010-2025 MHz band which could unduly delay an auction of this spectrum.

7 Recommendations

Table 10 provides a summary of our main recommendations across the four bands.

Table 10: Summary of main recommendations for the four bands

Band	Main recommendations
410-415 & 420-425 MHz	➢ Avoid unnecessary delay in assignment given scarcity of spectrum for digital PMR ➢ Clarify key issues prior to any assignments: reconfiguration of the spectrum; Fylingdales coordination; updating reference network to reflect most likely use (localised PMR transmitters rather than a national PAMR network) ➢ Further work by Ofcom required to define role and responsibilities of band managers and build market awareness of this opportunity ➢ Provided Ofcom believes that the band management role is viable and that it can establish a framework within 2005/06 timescale: ▫ Assign one or two national licences (depending on availability of spectrum following any award to public safety uses) ▫ Auction licence(s) using a simple sealed bid or ascending bid auction format ➢ Otherwise, license on a transmitter basis using FCFS and AIP, but consider: ▫ integrating sealed bids with planning tool to resolve conflicts in demand hot spots; and ▫ including provision for future transfer of band management rights from Ofcom to private parties
872-876 & 917-921 MHz	➢ Packaging: One nationwide paired block ➢ Assignment by auction using a first price, sealed bid format (possibly with ascending bid phase if more than two bidders) ➢ Consider preceding auction with demand evaluation phase to assess whether it is appropriate to release the spectrum at all under current market conditions ➢ Obligations imposed by coordination with neighbouring GSM spectrum must be clarified in advance of any auction

Recommendations

2010-2025 MHz	➢ Packaging: Three blocks of 5MHz ➢ Assignment by auction combined with the 2290-2300 MHz blocks (subject to timely resolution of legal issues concerning EU harmonisation in this band) ➢ Sealed bid combinatorial auction format ➢ Auction to be scheduled as soon as possible owing to impact on innovation in fixed wireless/mobile data/broadband provision ➢ Case for delay until 3G expansion band due to be allocated is weak
2290-2302 MHz	➢ Packaging: Two blocks of 5MHz (2290-2300 MHz) ➢ Retain remaining 2MHz for assignment with the 2302-2310 MHz band ➢ Assignment by auction combined with the 2010-2025 MHz blocks (subject to timely resolution of legal issues concerning EU harmonisation in the 2010-2025 MHz band) ➢ Sealed bid combinatorial auction format ➢ Auction to be scheduled as soon as possible due to impact on innovation in fixed wireless/mobile data/broadband provision

8 Next steps

In this section, we summarise the next steps that Ofcom could take in order to implement our recommendations.

Next steps for the 410-415 & 420-425 MHz bands:

- Clarify outcome of negotiations with the MoD on reconfiguration of the spectrum. The most attractive outcome from a market perspective would be 2 x 4MHz of spectrum contiguous, from 410-414 and 420-424 MHz.
- Publish official statement on the constraints imposed on use of this band owing to coordination with the Fylingdales radar.
- Update reference network to reflect most likely use – localised PMR transmitters rather than a national PAMR network.
- Determine extent of public safety reservation of this band, if any.
- Review viability of multiple band managers for this band in light of size of public safety reservation.
- Develop programme to promote and explore the band management model.
- Depending on expectations for band management programme, either develop detailed rules for: (a) auction of national licence(s); or (b) hybrid model of FCFS with AIP combined with simple market mechanisms for hot spots with strong excess demand.

Next steps for the other bands:

- Clarify legal obligations with respect to EU harmonisation for the 872-876 & 917-921 MHz band and 2010-2025 MHz bands.
- Develop detailed rules for a combined auction of the 2010-2025 MHz and 2290-2300 MHz bands. Consider possible contingency plans for separate auction in the event that release of the 2010-2025 MHz band is unduly delayed owing to legal issues related to EU harmonisation.
- Investigate possible licence exempt uses for the 872-876 & 917-921 MHz band.
- Evaluate case for holding back the 872-876 & 917-921 MHz band from assignment for licensed use (assuming no viable licence exempt uses are identified), pending more concrete evidence of demand for licensed use.