



Final report for Ofcom

Preparatory study for UHF
spectrum award

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Annex A: Technology compatibility issues

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Annex C: External value of candidate uses for the digital dividend spectrum

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0 Executive summary

This report has been prepared by Analysys Consulting Limited (Analysys), Mason Communications Limited (Mason), Aegis Systems Limited (Aegis), DotEcon Limited (DotEcon) and Damian Tambini as a summary of the work undertaken on a study of the award of UHF spectrum for the UK Office of Communications (Ofcom).

0.1 Background

The switchover to digital television in the UK (digital switchover, DSO) will release spectrum for new uses (so-called *digital dividend* or *released* spectrum) comprising of a total of 112MHz made up of $14 \times 8\text{MHz}$ channels. In addition, *interleaved* spectrum within the 32 channels to be used for digital terrestrial television (DTT) is potentially available for other uses.

Ofcom has also asked us to consider options for including two further channels in this award. Both Channel 36, currently used for aeronautical radar, and Channel 69, currently used for PMSE, may become available for new uses. The current use of UHF spectrum, and the position of the released spectrum and Channels 36 and 69, is illustrated in Exhibit 0.1 below.

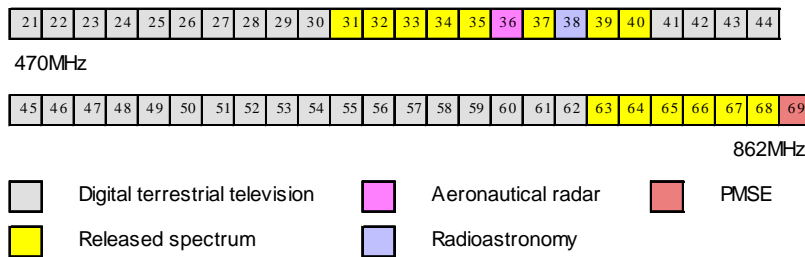


Exhibit 0.1:
UHF spectrum following digital switchover [Source: Ofcom]

The digital dividend spectrum is probably Ofcom’s most significant release of spectrum as outlined in its Spectrum Framework Review Implementation Plan – Interim Statement of July 2005, because of both the amount of spectrum to be released, and the value of UHF spectrum: the propagation characteristics of this band make it well suited to support a wide range of broadcast, mobile, and fixed applications.

Ofcom’s spectrum management policy as set out in the Spectrum Framework Review is to allow the market to determine allocation (uses) and assignment (users), whenever possible; however, Ofcom also recognises that the award process may be affected by a number of issues such as international constraints on usage, compatibility of different uses and potential market failures. The objective of this study, therefore, is to provide evidence to help Ofcom identify the optimum framework for releasing the available digital dividend spectrum to the market in a way that will maximise benefits for the economy and society over time. The scope included the provision of advice to Ofcom on the design of the award process, the timing of award(s), the packaging of spectrum, and licence conditions.

Exhibit 0.2 summarises our overall approach to the study, including the identification of potential uses of digital dividend spectrum, a technical and economic assessment of these candidate uses, the design of the award process, and consideration of potential risks of market and regulatory failure. A summary of the results of our analysis is presented below.

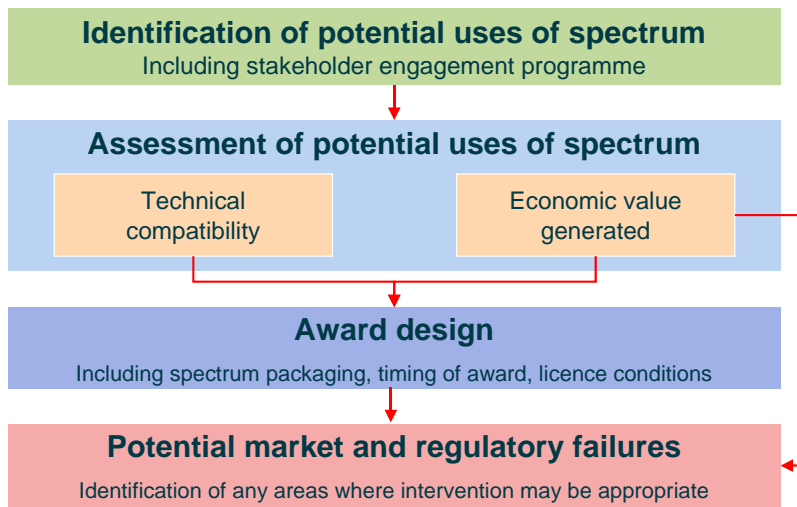


Exhibit 0.2:
Approach to study

0.2 Potential uses of digital dividend spectrum

During the study, we conducted an extensive stakeholder interview programme in order to identify the nature of market demand for digital dividend spectrum. As well as a series of stakeholder interviews, this programme included the issuing of a questionnaire. In total, we received input from 48 organisations (nine of which were via written responses to our questionnaire), including existing and potential spectrum users (e.g. DTT users, mobile multimedia users), equipment manufacturers and other organisations. We also held two stakeholder events to discuss our approach and findings on potential uses of the spectrum.

From this programme, we identified the potential uses of digital dividend spectrum listed below.

DTT Digital dividend spectrum could be used to offer DTT services in addition to the six (post-DSO) DTT multiplexes, in either the standard definition (SD) or high-definition (HD) format, and either on a free-to-view or subscription basis.

Local TV The spectrum could be used to offer digital terrestrial television targeted at local communities.

Mobile multimedia The spectrum could be used to offer broadcast services to mobile handsets, most notably mobile TV but also other multimedia services such as radio.

Programme-making and special events (PMSE) UHF spectrum is currently used for radio microphones, in-ear monitors (IEMs), talkback and point-to-point audio links. There is a desire that these bands continue to be available for these services, and possibly for other PMSE uses.

Cellular/broadband wireless access services Digital dividend spectrum could potentially be used to provide cellular or BWA services. Technologies that could be deployed include 3G (and enhancements of 3G), WiMAX and UMTS TDD.

Private mobile radio and public access mobile radio Private mobile radio (PMR) systems are used by companies such as taxi operators. There appears to be little demand for digital dividend spectrum for PMR use.

Public access mobile radio (PAMR) is used by organisations such as ambulance services. There may be interest in offering video services for the emergency services via PAMR.

Licence-exempt services The spectrum could be used to offer a number of licence-exempt services including: wireless ‘last-mile’ applications (such as home networks), broadband wireless access (BWA), safety-of-life applications, transport congestion alleviation, automated buildings, RFIDs, and medical sensors.

Assessment of the above uses was undertaken from the perspective of both technical compatibility and total value to society, and the results are described in the following chapters. Please note that the study team recognises that there are other potential uses of the digital dividend spectrum. For example, towards the end of the study, we received a submission from a stakeholder interested in using the spectrum for satellite broadcasting. Unfortunately, it was not possible at this stage to include this use in the technical and economic assessment. However, we remind the reader that our award process design work

focused on maximising the scope for the market to determine the best use of the spectrum, rather than limiting it to any particular use or uses.

0.3 Compatibility of alternative uses of digital dividend spectrum

The objective of our analysis was to consider compatibility issues associated with the alternative uses of digital dividend spectrum described above. As shown in Exhibit 0.3 below, our assessment included consideration of :

- the different underlying spectrum requirements of the candidate uses (e.g. power levels, and whether they involve one-way or two-way transmissions)
- constraints arising from international use of the spectrum, e.g. as embedded in the Regional Radiocommunications Conference (RRC-06) agreement, in terms of both restrictions on UK use and scope for harmful interference to be caused to UK users
- constraints arising from harmful interference to other services which will be using the UHF spectrum following DSO, including the six 'base' DTT multiplexes¹
- scope for interference between alternative potential uses of the digital dividend spectrum.

¹

Following digital switchover, a total of six DTT multiplexes will be available in the UK. We call these the six 'base' multiplexes to distinguish them from any additional multiplexes that may be deployed using the digital dividend spectrum.

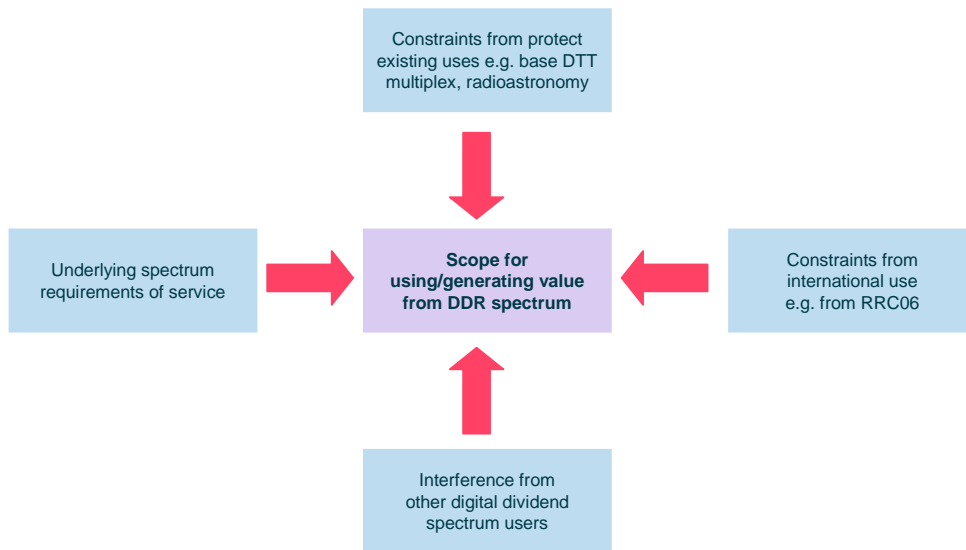


Exhibit 0.3: Compatibility issues associated with use of digital dividend spectrum

Details of our assessment are provided in Chapter 3 and a supporting Annex A. In summary, the principal issues are as follows:

- Some potential users of the digital dividend spectrum have preferences for specific channels:** Spectrum stakeholders do not regard individual digital dividend channels as being alike. Certain users would prefer channels within a certain range, e.g. below 750MHz for mobile multimedia users, or Channel 69 for PMSE users. Users may also prefer specific individual channels in specific locations, e.g. Channels 33 and 37 in the Crystal Palace area in order to fully take advantage of the transmission rights accorded to the UK at RRC-06.
- Digital dividend users could incur costs to protect the six base DTT multiplexes and other existing services:** Usage of the released and interleaved spectrum could cause harmful interference to reception of the six base DTT multiplexes and also other existing users (e.g. radioastronomy in Channel 38). In respect of the released spectrum, such issues are likely to arise primarily in areas where new usage of the spectrum is in an adjacent channel to one used by a base DTT multiplex. One potential solution to this problem is the deployment of low-power DTT filler stations co-sited with new transmitters. Interference issues could also occur where a base DTT multiplex is using a channel nine channels below the new use, due to ‘image channel’ interference (see

Chapter 3 for further details). In respect of new services using the interleaved spectrum, sufficient geographic separation will need to be maintained between the new service areas and existing DTT coverage areas.

- **Adjacent channel interference issues between new users of digital dividend spectrum could be significant:** Ideally, the solution to such interference, caused by the practical limitations of transmitter and receiver filtering, would rely on sufficient co-ordination between spectrum users to minimise ‘hole-punching’ and other effects (see Chapter 3 for an explanation of these effects). If such co-ordination does not occur, large frequency separations (‘guard bands’) of 5MHz or more on both sides could be required between individual users in adjacent spectrum.
- **Use of mobile uplink services (e.g. cellular, BWA) will require sufficient frequency separation to protect other (existing and new) users.** Such usage of the digital dividend spectrum could cause particular problems for existing DTT receivers if the mobile uplink usage is in an adjacent channel or image channel (see Chapter 3 for further details). The deployment of DTT infill transmitters is not a practical solution where the interfering transmission is from one or more mobile terminals.
- **Packaging the released spectrum into multi-channel blocks would minimise adjacent channel interference but may not suit all potential users.** Packaging the released spectrum into multiple adjacent channel blocks would help to minimise adjacent channel interference issues; however, we understand that certain users may seek a mix of channels from different parts of the band. For example, a DTT user wishing to fully benefit from the transmission rights accorded to the UK at RRC-06 may seek a mix of channels from lower and upper blocks of the released spectrum.

0.4 Value derived from alternative uses

The objective of our analysis was to understand the ‘total value’ that each of the candidate uses of the digital dividend spectrum could contribute to the economy and to society.² In

² We use the term ‘total value’ throughout to refer to the sum of all benefits and costs associated with the allocation of spectrum to a particular service. In economic literature, this measure of overall value is often also referred to as ‘social value’.

particular, our focus was on assessing the *incremental* benefits that could result from the use of digital dividend spectrum to provide each service. If a service could only be provided using the UHF spectrum, total value would include all benefits associated with the service. However, where the service could be provided using an alternative delivery platform, such as another spectrum band or wireline solution, we are only concerned with the additional benefits from using digital dividend spectrum over-and-above those that would be realised from using alternatives.

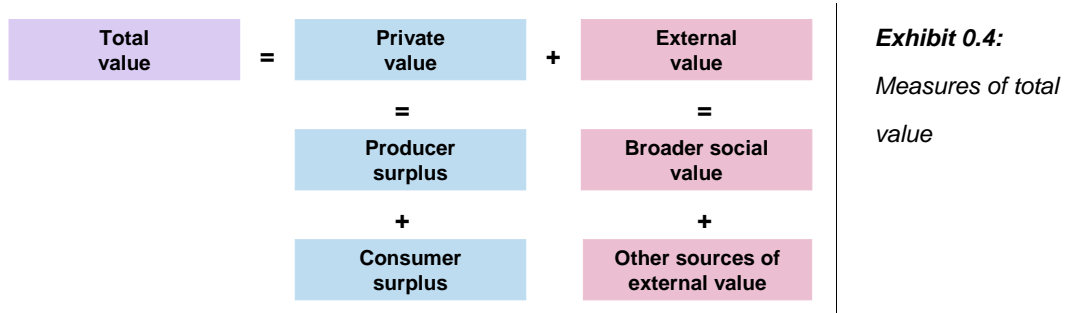
For the purposes of our assessment, we have considered three measures of total value:

- **The private value derived from use of the spectrum** captures the direct benefits to individuals from their own consumption of the service (i.e. the value consumers place on the service), less the costs of producing the service.³ In economic terms, this is equal to the sum of consumer and producer surplus.
- **The external value** captures any additional benefits to consumers or third parties not reflected in the value of the service to consumers. The total value comprises the private value plus any external value. This broad definition captures all types of externalities,⁴ such as investment spillovers (knock-on benefits for other sectors of the economy), non-internalised network effects, and what we call ‘broader social values’ (value that the public derives from services because of their broader contribution to society). Externalities are not necessarily positive; we have also considered possible negative external effects, such as interference with existing services, or health concerns associated with certain transmissions.
- **The willingness to pay for spectrum** by potential purchasers of the spectrum (e.g. network operators). This is, in economic terms, a *proportion* of the producer surplus that would be derived from providing the service.

3 To the extent that the willingness to pay is expressed for the predicted level of take-up of services, it includes a portion of network benefits, namely those that would be internalised by the market. This would include network benefits anticipated by both consumers and service providers (e.g. economies of scale in handset or roaming benefits).

4 Externalities are the unintended spillover effects of economic activity on third parties.

The relationship between total value, private value and external value is summarised in Exhibit 0.4; note that willingness to pay is a proportion of producer surplus.



The purpose of analysing total value is to inform our understanding of how well a market mechanism could be expected to allocate spectrum to the services that can use the spectrum most efficiently and generate the greatest value for the economy and society. A key assumption underpinning the use of auctions for assigning spectrum licences is that bidders' relative willingness to pay for spectrum will reflect the relative total value that candidate services will create. willingness to pay is normally a good indicator of total value if all bidders plan to deploy similar services, but it may be a less reliable indicator if bidders are competing for spectrum to supply different (non-substitutable) services.

Our approach to the assessment of private value is summarised in Exhibit 4.2 below. As indicated above, our underlying approach was to identify the *incremental* benefits of the use of digital dividend spectrum for each of the potential services. We undertook this by:

- developing a number of demand (macro) scenarios for the evolution of the markets associated with each of the services under consideration
- identifying the potential uses and benefits of digital dividend spectrum if it were available for each service under consideration, and what the next-best alternative(s) would be if digital dividend spectrum were *not* available
- quantifying the incremental benefit (revenues less costs) to potential purchasers of digital dividend spectrum and therefore assessing what the willingness to pay for spectrum would be
- quantifying the incremental benefit to consumers and producers if digital dividend spectrum were available for the service under consideration.

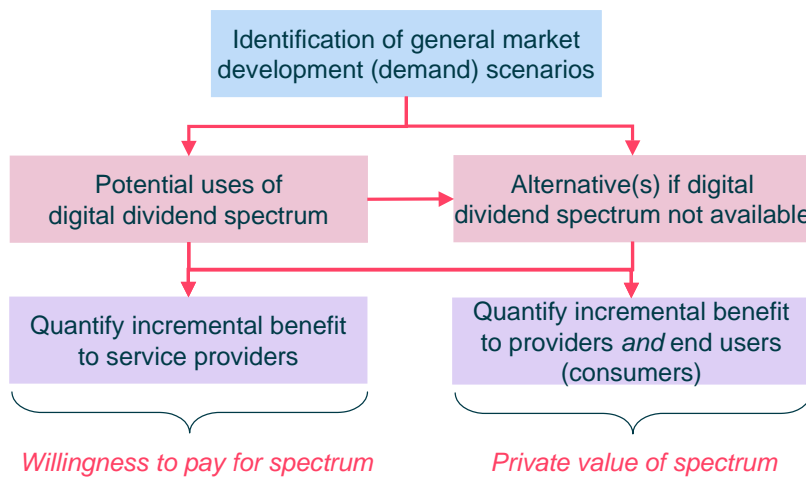


Exhibit 0.5:
Overview of approach to assessment of private value

Our assessment of external value included extensive consideration of sources of **broader social value**. This term is used to describe the value derived from services because of their broader contribution to society, for example because a service contributes to a better-informed democracy, higher educational standards or a more inclusive society. This category of external value is often also referred to as ‘public’ or ‘citizen’ value. In addition we also considered **other sources of external value**. These include a variety of other externalities, such as investment spillovers (knock-on benefits for other sectors of the economy), non-internalised network effects, and health effects.

Further details of our economic analysis can be found in Chapter 4 and Annex C. The principal issues we identified are as follows:

- **Uncertainty over magnitude of private value generated from use of digital dividend spectrum:** Our modelling work indicated there is considerable uncertainty over the total private value that could be generated from use of the digital dividend spectrum. Our estimates range from GBP2.5 billion to GBP30 billion, as a result of the uncertainties associated with the potential uses of digital dividend spectrum (e.g. the value of additional HDTV channels to individuals, or the future take-up of mobile multimedia services).
- **Duration of spectrum usage rights.** Our modelling suggests that for those potential uses which would involve a significant deployment of infrastructure (e.g. additional DTT transmitters, mobile multimedia broadcast network, etc.), the vast majority of

value will be captured over 15 years, and there will be relatively modest additional value over 20 years. By contrast, there would be a significant loss in value if the period were reduced to 10 years, although valuations generally remain positive.

- **Timing of spectrum availability and phasing of release of spectrum.** Delays to the award of digital dividend spectrum (e.g. to 2010 or 2012 instead of release in line with DSO from 2008 onwards) would have differing impacts depending on the potential use of the spectrum. A delay to 2010 could have a major impact on the mobile multimedia market if there is strong consumer interest in services and alternative networks have not been deployed in other spectrum bands (e.g. L-Band). However, a delay to 2010 or 2012 could potentially benefit PMSE users if they were allowed to continue to use the spectrum in the interim period on a similar financial basis as under the current licensing regime.
- **External value assessment.** Our research suggests that although there are significant external value or benefits associated with many of the candidate services that could use digital dividend spectrum, the *incremental* external value generated as a result of these services making use of digital dividend spectrum are relatively modest.
- **Possible scope for a market failure in relation to additional DTT deployments (including local TV).** Under certain modelling assumptions, we found that the willingness to pay for additional spectrum for DTT as a proportion of the private value that could be generated was lower than the corresponding willingness to pay/private value ratio for other services. This may be a consequence of the advertising model being less efficient at capturing private value than the revenue-generating models of other services, where revenues are linked directly to the value placed on particular services by their end users, as expressed in their willingness to pay for the service. Using alternative modelling assumptions (e.g. the value to individuals of additional TV channels), the willingness to pay as a proportion of private value is in line with other services. Our external value assessment also indicated that there may be modest incremental external value benefits if digital dividend spectrum were to be used for the provision of more TV services.
- **Possible scope for a market failure in relation to PMSE.** Our assessment suggests that the willingness to pay for spectrum by this sector may be low as a proportion of

total value in comparison with other potential uses of digital dividend spectrum, owing to the difficulty of realising revenues from a diverse set of users (especially community users) that reflect the true value that PMSE is generating. Furthermore, it is possible that our modelling may be understating the total value of professional PMSE use, owing to the difficulty of modelling the complex value chain into which PMSE is an input. This would in turn suggest that we may be understating the willingness to pay for spectrum.

- **Reserving spectrum for licence-exempt services.** Our analysis concluded that the economic benefits of making spectrum available for licence-exempt services is unlikely to outweigh the opportunity cost of denying the use of the spectrum for licensed services. Further details of our assessment can be found in Annex B.

0.5 Award process design

In line with Ofcom’s overall approach to spectrum management, whenever appropriate spectrum should be awarded on a technology and service-neutral basis via a market mechanism, i.e. an auction. We consider the key factors that determine the ultimate choice of packaging and auction design, and set out the available options for:

- packaging the spectrum into lots that can be offered to potential bidders in an auction
- defining usage rights attached to those spectrum lots
- designing an auction process for the allocation and assignment of the spectrum
- the timing of the award of digital dividend spectrum.

Our analysis at this point focuses on how a market-led process for the allocation and assignment of digital dividend spectrum should be designed. It does not address the potential implications of market failure risks, which could in principle require intervention in the award design. Market failure risks are addressed separately below. Our main findings are summarised in the following.

Packaging

There are a wide variety of packaging options for both the released and interleaved spectrum, including offering the spectrum in the form of individual 8MHz channels, aggregating adjacent channels into a small number of larger lots, and – for the interleaved spectrum – carving out regional lots.

The best approach in terms of maximising flexibility for different candidate uses and users would be to package the released spectrum into national 8MHz channels rather than aggregating channels. However, such an approach puts great emphasis on using auction design to manage bidder aggregation risks, and designing usage rights that enable bidders to effectively manage the uncertainty over their prospective interference environment in a technology-neutral environment. It is possible that potential bidder uncertainty over the design of usage rights could be eased by using larger lots (aggregations of contiguous 8MHz channels), but this would reduce bidder flexibility (relative to using 8MHz channels at individual lots) and may preclude some potentially efficient award outcomes.

For the interleaved spectrum, packaging spectrum into 8MHz channels encumbered by DTT is a plausible strategy; however, there is a good case for carving out a limited number of regional lots from the interleaved spectrum based on major service regions (MSRs), which correspond to geographic areas of high demand, such as London, Manchester, etc. Packaging some lots as MSRs, corresponding to urban demand ‘hotspots’, would mean that regional demand from some candidate services (such as local TV) could be more easily addressed in the primary award stage, thus reducing their reliance on the secondary market.

Usage rights

The way in which usage rights are specified will have a big impact on the potential uncertainty for bidders about their prospective interference environment in a technology-neutral environment. We consider the scope for different ways of mitigating interference, including obligations to provide adequate separation, and rights and obligations that would facilitate the co-siting of transmitters (which would seem to be an efficient way of mitigating interference problems for adjacent broadcast uses).

We conclude that it should be feasible to define effective usage rights for 8MHz national lots (plus a limited number of regional lots in the interleaved spectrum, if required), and that therefore this packaging option should be viable. However, further work is required to clarify how obligations for co-ordination (especially co-siting) and minimum frequency separations between particular pairs of adjacent technologies would be defined in detail.

Auction design

We explore various options for the design of the award process, highlighting their relative strengths and weaknesses. We rule out single-round sealed bid options, and consider different variations of multiple-round formats. Specifically, we consider three potential auction formats:

- **A standard simultaneous multiple round auction (SMRA)**, potentially with enhanced activity rules, such as withdrawal penalties and augmented switching. This is the simplest approach from a design perspective, but leaves bidders who are seeking multiple lots exposed to potential aggregation risks, which may be sufficiently strong to prevent an efficient auction outcome.
- **A package-bid SMRA**, in which bidders can make multiple, exclusive bids for packages of lots, as well as individual lots. This approach addresses the aggregation risk concerns associated with the standard SMRA format, but may be unduly complex to implement if (as is likely) there are a large number of lots in the auction.
- **Two versions of a clock-sealed bid hybrid**, one with each lot as a unique category (predetermined lots) and the other with a smaller number of categories of similar (generic) lots. These approaches are a natural extension of the standard ascending clock auction to the situation where there are a number of different categories of lots, and bidders have demands for packages of lots across categories. It facilitates package bidding but is less complex than the package-bid SMRA for both the bidders and the auctioneer.

The choice of auction format is closely tied to the choice of packaging option, and whether the awards of the released and interleaved spectrum are integrated or held separately. All the proposed formats would require the development of bespoke auction rules.

Timing of the award

Holding an auction in 2008 (or as soon as practically possible thereafter), will allow winning bidders to start using digital spectrum as soon it becomes available (initially on a regional basis). This approach should maximise scope for creation of value for UK consumers and companies.

Holding a combined auction of released spectrum (including Channel 36) and interleaved spectrum would minimise substitution and aggregation risks for bidders. However, depending on the packaging approach, it may also significantly complicate the auction design. A pragmatic decision will be required on whether it is possible to combine the awards, based on a trade-off between these factors.

0.6 Assessment of potential market and regulatory failures

Market mechanisms for the allocation and assignment of spectrum generally produce optimal outcomes provided that willingness to pay for spectrum is sufficiently closely tied to the value that a spectrum user can generate – e.g. in cases where willingness to pay is derived from the bidder’s projected profits,⁵ and profits account for a similar proportion of total value across all potential bidders. An auction will ensure that spectrum will be assigned to those bidders with the highest willingness to pay. Therefore, provided that all bidders’ expected profits are closely related to the total value that they can generate, an auction will ensure that licences are assigned to those who can generate most value. However, if the relative willingness to pay of bidders across different uses is not a reasonable reflection of the relative total value that they can generate, then using a market mechanism for the *allocation* of radio spectrum may fail to produce an efficient outcome.

⁵ This ignores the fact that some prospective bidders in an auction might be not-for-profit organisations (e.g. the BBC) that are pursuing different objectives, and therefore implies that a different analysis of the drivers of their willingness to pay for spectrum will be required.

There are three reasons why there may be market failure in an auction:

- **Structural differences** between downstream service markets may lead to differences in the ability of bidders to capture PV, thus distorting their relative WTP as an indicator of total PV.
- **Transaction costs** may drive a wedge between private value and willingness to pay.
- There may be significant **external value** associated with some services which by definition is not reflected in the willingness to pay.

In considering the risk of market failure, it is necessary to consider for each candidate service whether there are any reasons why the willingness to pay for spectrum of those wishing to provide this service (relative to the willingness to pay of those providing other services) might not properly reflect the total value that would be generated by that use (relative to other potential uses).

Identifying the potential for market failure does not in itself provide justification for regulatory intervention. The ‘cost’ of a market failure is the welfare loss suffered as a result of markets failing to produce the efficient outcome. Only if the cost of intervening, including the resource cost of intervention and the risk of regulatory failure, is smaller than the cost of the market failure will intervention be beneficial.

For this project, we have set out a framework for identifying and analysing potential sources of market failure, and considering potential remedies and associated risks of regulatory failure. We also apply the framework to consider potential sources of market failure in relation to each of the candidate services in an auction of digital dividend spectrum. It was beyond the scope of this project to consider in detail any options for regulatory intervention and any associated concerns about regulatory failure.

Overall, we find that there are a number of reasons why the ratio of willingness to pay to total value generated by the candidate uses may differ. This is not surprising, given that the digital dividend spectrum is potentially usable for a wide range of services with fundamentally different characteristics. Our analysis indicates that some candidate uses appear more likely to be subject to market failure risks. For example:

- The ability of a PMSE band manager to extract the full value of PMSE use may be limited owing to the difficulty of co-ordinating demand across many small users. Our assessment suggests that while there is scope for a PMSE band manager operating on a commercial basis to coordinate demand from professional users effectively, the disparate nature of community users suggests that any attempt to coordinate their spectrum use would be expensive and may not be worthwhile. In addition, the existing model for funding PMSE – which relies on administrative fees that bear little relation to the opportunity cost of spectrum use – is not viable in an auction context.
- For broadcasters offering their channels free-to-air, there could be concern that the willingness to pay for spectrum may be deficient as a proportion of total private value associated with incremental DTT capacity – whether for SD, HD or local TV. This reflects their dependence on commercial revenues (such as advertising revenues) that – unlike subscription revenues – are not closely tied to the valuation placed upon these services by their end users. However, our modelling work suggests there is uncertainty over whether the willingness to pay for spectrum amongst free-to-air broadcasters will be deficient as a proportion of total value; this depends upon the value that consumers attach to incremental channels.
- Our external value research identified some potential concerns related to HDTV, local TV and PMSE. For example, there is a plausible, albeit speculative argument that under-provision of HDTV on DTT might erode the wider value of DTT, and potentially even erode its viability as a leading mass-market platform. However, it is unclear whether the DTT platform would require additional spectrum to avoid such under-provision.

In summary, there is no clear and strong evidence with regard to the magnitude of these effects. Although some candidate uses – namely PMSE and free-to-air DTT (including HDTV and local TV) – appear to be more likely to be subject to market failure risks, there is no conclusive proof that intervention is absolutely necessary. Additionally, before reaching any view on the appropriateness of intervention it would be necessary to consider the available remedies in order to identify the likely opportunity cost of intervention and the risk of regulatory failure.



1 Introduction

This report has been prepared by Analysys Consulting Limited (Analysys), Mason Communications Limited (Mason), Aegis Systems Limited (Aegis), DotEcon Limited (DotEcon), and Damian Tambini as a summary of the work undertaken during a study of the award of UHF spectrum for the UK Office of Communications (Ofcom).

1.1 Background to the study

The digital switchover (DSO) of TV services is expected to take place in the UK between 2008 and 2012. This process will make available 112MHz of *released* spectrum (14×8MHz channels) in Bands IV and V for other services (see Exhibit 1.1 below) – the so-called “digital dividend”. In addition, *interleaved* spectrum within the 32 channels to be used for digital terrestrial television (DTT) is potentially available for other uses.

Ofcom has also asked us to consider options for including two further channels in this award. Both Channel 36, currently used for aeronautical radar, and Channel 69, currently used for PMSE, may become available for new uses.

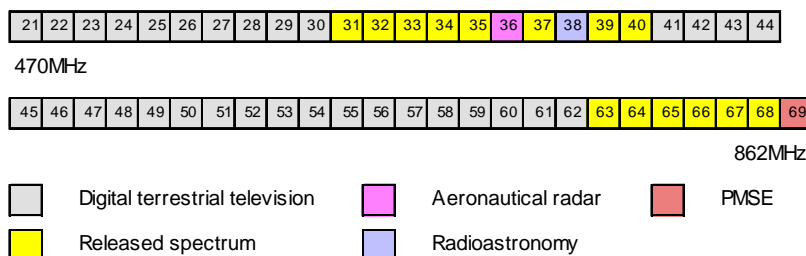


Exhibit 1.1:
UHF spectrum
following digital
switchover [Source:
Ofcom]

All this spectrum lies in a frequency range with propagation characteristics well suited to supporting a wide range of broadcast, mobile, and fixed services, and is an extremely valuable resource. A significant proportion of the value derived from the use of the radio spectrum is generated by applications in spectrum between 470MHz and 862MHz. This is probably Ofcom’s most significant release of spectrum, as outlined in its Spectrum Framework Review Implementation Plan – Interim Statement of July 2005. In this document Ofcom indicated that it is “*intending [to] make this spectrum available by market process, as there is clearly a variety of competing users for the spectrum.*” Such an approach is consistent with Ofcom’s spectrum management policy as set out in the Spectrum Framework Review, however there are several complexities associated with this band that need to be considered, including:

- **spectrum requirements of services** – the range of services that could use the spectrum have a wide variety of requirements (e.g. channel width, paired versus unpaired spectrum)
- **compatibility of services** – compatibility issues could result from the wide-ranging network topologies of the potential uses (e.g. high-power broadcast transmissions, dense base-station networks, low-power, short-range devices)
- **international usage** – the use of the spectrum in other countries (e.g., for broadcasting) places constraints on how individual channels can be used in the UK in terms of interference to and from users of the spectrum in other countries
- **potential market failures** – some of the potential uses of the spectrum may have benefits (e.g., broader social benefits) that might not be reflected in participants’ willingness to pay for spectrum in a commercial auction.

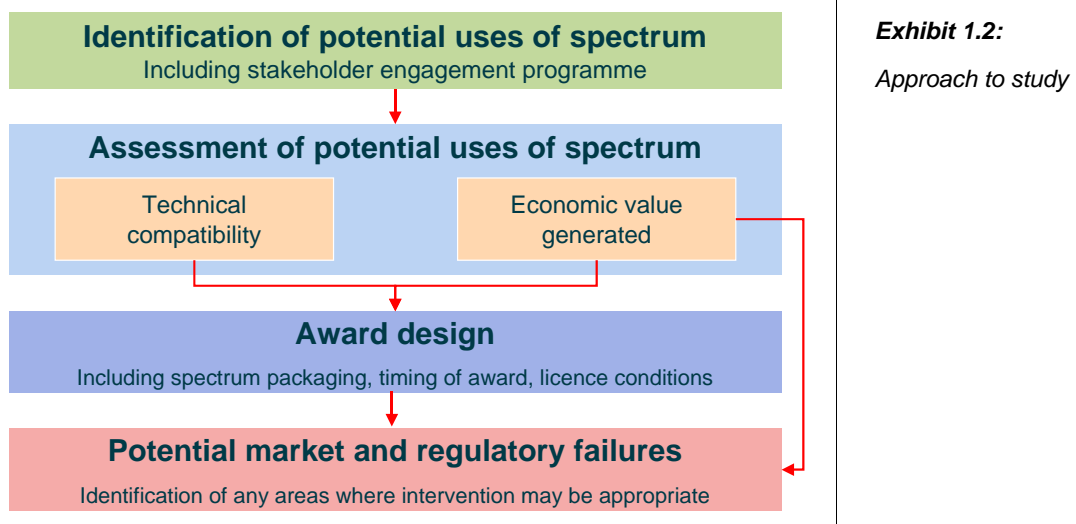
Ofcom has commissioned this study to consider such issues to help it develop its approach for the award of the available spectrum.

1.2 Study objectives and approach

The underlying objective of the study is to provide evidence to help Ofcom identify the optimum framework for releasing the available digital dividend spectrum in a way that will maximise benefits for the economy and society over time. This includes the provision of

advice to Ofcom on the design of the award process, timing of award(s), packaging of spectrum, and licence conditions.

Exhibit 1.2 summarises our overall approach to the study.



The study included the activities listed below:

- **Identification of potential uses of digital dividend spectrum** – this involved the identification of alternative uses of the spectrum, the interest from different types of organisation in acquiring the spectrum, and the spectrum requirements (amount, packaging) of each potential use.
- **Technical compatibility analysis** – this included an assessment of compatibility issues between alternative uses of the spectrum including consideration of constraints imposed by international agreements, the need to protect other users of UHF spectrum and an assessment of the scope for combining different services or technologies in the available spectrum.
- **Total value generated** – this involved the quantification of the potential economic benefits arising from alternative uses of the spectrum, including direct benefits to individuals (private value), and any additional external benefits (external value).

- **Award process design** – identification of options for the award process, including spectrum packaging, timing of award, licence conditions and nature of the award process itself.
- **Market and regulatory failures assessment** – identification of any potential market and regulatory failures.

It is important to note that the study does not aim administratively to determine the future use of the digital dividend spectrum, nor seek to limit the potential uses for which the spectrum would be available. However, it is necessary to identify potential uses of the spectrum and the compatibility of these in order to assess the effectiveness of different award processes and identify the optimum approach.

A key component of the study has been the involvement of industry stakeholders, through an extensive interview programme, plus a questionnaire and two project workshops. We would like to thank all stakeholders for their assistance throughout the project and the invaluable information and feedback they have provided to us.

1.3 Structure of this document

The remainder of this document is structured as follows:

- Section 2 discusses the demand for digital dividend spectrum and alternative uses
- Section 3 summarises the results of our assessment of the compatibility of alternative uses of the spectrum
- Section 4 summarises our assessment of the total value that could be derived from the different uses of the spectrum
- Section 5 presents our analysis of options for the award process
- Section 6 discusses our assessment of potential market and regulatory failures.

A number of supporting annexes, listed below, provide additional detail on the issues discussed in this report.

- Annex A provides details of our assessment of the technical compatibility issues between different potential uses of digital dividend spectrum
- Annex B assesses the use of some of the spectrum for licence-exempt uses

- Annex C provides details of the assessment of external value from different uses
- Annex D presents our analysis of the options for the packaging and award process design
- Annex E provides details of our assessment of potential market and regulatory failures.

2 Demand for digital dividend spectrum

2.1 Introduction

In order to understand the market demand for digital dividend spectrum, we have conducted an extensive stakeholder interview programme. As well interviews, this programme included questionnaires and two workshops. In total, we received input from 48 organisations (9 of which were via written responses to our questionnaire), including existing/potential spectrum users (e.g., DTT users, mobile multimedia users), equipment manufacturers and other organisations. Exhibit 2.1 below lists these organisations.

<i>Potential/existing users</i>	<i>Number of institutions interviewed</i>
DTT	10
Mobile multimedia/cellular	7
Network operators	2
Broadband Wireless Access (BWA)	3
Private Mobile Radio (PMR) and Public Access Mobile Radio (PAMR)	2
PMSE	3
<i>Manufacturers</i>	
DTT manufacturers	1
Mobile multimedia/cellular manufacturers	3
BWA manufacturers	2
PMR manufacturers	2
PMSE manufacturers	1
Other manufacturers	2
<i>Other</i>	
Other organisations	13

Exhibit 2.1: *Companies and institutions interviewed/from which we received a questionnaire response [Source: Analysys, 2006]*

Please note that although each respondent has been classified into a use and type of organisation (e.g. DTT manufacturer) they may have given views on other uses: for example, some of the broadcasters gave views on DTT, mobile TV and Programme Making and Special Events (PMSE).

In addition to the interview programme and questionnaires, the consulting team has hosted two events to discuss our approach and findings with stakeholders. The inputs from stakeholders at these events have been fed into the analysis.

The remainder of this chapter summarises the potential uses of digital dividend spectrum as identified by the stakeholder interviews, and then provides a brief summary of the key observations from the stakeholder consultation, including the level of interest in the spectrum and the spectrum requirements. Please note that more details regarding the spectrum requirements are included in Section 3.2.

Using the findings from the interviews, we identified the potential uses of digital dividend spectrum listed below.

- **DTT** – digital dividend spectrum could be used to offer additional DTT services to the existing six DTT multiplexes, in either the standard definition (SD) or high-definition (HD) format and either on a free-to-view or subscription basis
- **Local TV** – the spectrum could be used to offer digital terrestrial television targeted at local communities
- **Mobile multimedia** – the spectrum could be used to offer broadcast services to mobile handsets, most notably mobile TV but also other multimedia services such as radio.
- **Programme-making and special events** – Bands IV/V are currently used for radio microphones, in-ear monitors (IEMs), talkback and point-to-point audio links.
- **Cellular/broadband wireless access services** – digital dividend spectrum could potentially be used to provide cellular or BWA services. Technologies that could be deployed include 3G (and enhancement of 3G), WiMAX and UMTS TDD.

- **Private mobile radio/Public access mobile radio** – there appears to be little demand for digital dividend spectrum for PMR, however, there may be interest in offering video services for the emergency services via PAMR.
- **Licence-exempt services** – this spectrum could be used to offer a number of licence-exempt services including: wireless ‘last-mile’ applications (including in-house entertainment networks), safety-of-life applications, transport congestion alleviation, automated buildings, RFIDs, medical sensors, wireless broadband.

2.2 Findings of the interview programme

This section summarises the likely demand for digital dividend spectrum as detected in the stakeholder interviews, broken down by service. It also considers the spectrum requirements that each service would have.

2.2.1 Digital terrestrial television

Interest in the spectrum

Throughout the stakeholder interviews we detected significant interest in using digital dividend spectrum for DTT. This came from two main groups of potential users.

- Existing free-to-view broadcasters, including PSB broadcasters, are interested in using this spectrum to facilitate the migration of the DTT platform to HD. They argued that HD was key to the long-term survival of the DTT platform.
- Other broadcasters/programme makers generally expressed interest in offering additional SD services on the DTT platform. Opinion varied about whether this should be for free-to-view or subscription services.

Interest was expressed in *national* services (and also *local* services: see Section 2.2.2), but there was relatively little interest in offering *regional* DTT services.

There was a consensus amongst these stakeholders that there are no credible alternative bands for these services. The use of any other bands would require new aerials be installed in viewers' homes.

Spectrum requirements

DTT users require unpaired 8MHz channels. Respondents ideally would like access to the channels that benefit from the high-power transmission rights (and interference protection rights) that the UK has secured at RRC-06 (e.g. Channels 33 and 37 at Crystal Palace) in order to deploy additional multiplexes. Whilst users acknowledge that it is possible to construct a DTT multiplex using alternative spectrum configurations, they indicate that these could result in additional transmitter stations being required, or poorer coverage. They may also require households to (a) deploy a new wideband aerial and/or (b) deploy a second aerial. Different users have very different requirements for such additional multiplexes:

- PSB broadcasters would like one or two multiplexes to carry HD services, each multiplex having the capacity to deliver two to three HD channels (assuming viewers have MPEG-4 set-top boxes). They argued that additional capacity will be critical as the DTT platform migrates to HD. The current capacity of the three PSB multiplexes will, they argue, not be sufficient to simulcast the five main PSB channels (BBC1, BBC2, ITV1, Channel 4 and Channel 5) in both SD and HD alongside the other existing PSB SD services. One (or possibly two) additional multiplexes with near-universal coverage would enable the migration of PSB programming to HD.
- Other broadcasters stated a preference for multiplexes that do not have any coverage obligations, as per the existing commercial multiplexes.

2.2.2 Local TV

Interest in the spectrum

We encountered interest in offering local TV services using this spectrum. This was mainly from two types of organisation:

- national PSB broadcasters looking to extend their services to local TV
- individual local TV organisations that either currently offer local TV services or potentially might look to offer such services in the future.

Stakeholders showed interest in local TV, not only in major cities but also in more rural areas.

Spectrum requirements

There are a several ways in which local TV could be implemented. *Add/drop technology* is one possible method; this technology involves the replacing of national programming channels with local content at individual sites of a national DTT multiplex. It was suggested that up to three slots on a national multiplex could be used for local TV, creating over 200 local TV channels. This technology could be implemented either on one of the six existing DDT muxes, or on any additional DTT muxes deployed in digital dividend spectrum.

Other methods for deploying local TV include using *individual low-power transmitter sites* to broadcast to local communities, or deploying a *national multiplex* dedicated to local TV: this would probably be a low-capacity multiplex using a modulation scheme such as Quadrature Phase Shift Keying (QPSK).

2.2.3 Mobile multimedia

Interest in the spectrum

A number of parties expressed interest in using this spectrum for mobile multimedia services (mobile TV, radio and other multimedia services). These included network operators, mobile operators and broadcasters. Interest was primarily in standalone broadcast networks such as Digital Video Broadcasting for Handhelds (DVB-H), Digital Multimedia Broadcast (DMB), or MediaFLO. However, few parties express a strong preference between these technologies. The view was that ‘add-on’ technologies to 3G networks (e.g., MBMS) are more likely to be deployed in 3G spectrum.

Trials to date suggest that there is demand for 16+ programming channels, and the majority of stakeholders suggest that they would be interested in offering 15–20 programming channels. Most of the stakeholders expressed interest in offering a nationwide service.

Concerns were raised about the late release of digital dividend spectrum, which may not be available nationwide until 2012. As a result a number of stakeholders stated that Channel 36 would be of particular interest to them if it were to become available earlier. Also some stakeholders suggested the possibility of initially deploying an urban service in L-Band (which may be available from 2008) and then extending the service to rural areas using UHF spectrum once it becomes available. The more favourable propagation characteristics of UHF would require fewer base stations. It is possible for an operator to deploy a nationwide service entirely in L-Band, however, they would require significantly more sites, and incur significantly greater costs, in order to do so.

Spectrum requirements

An 8MHz channel would be sufficient to offer approximately 20 programming channels, the amount suggested as desirable by recent trials (e.g., the DVB-H trial in Oxford in 2006). By combining contiguous channels, an operator could increase the number of channels offered.

An operator would be able offer a nationwide service using a single-frequency network with just one 8MHz channel. However, a multi-frequency network (MFN) would enable them to offer regional content and potentially interleave with other services (e.g., DTT).

2.2.4 PMSE

Interest in the spectrum

PMSE is an existing user of the UHF spectrum. JFMG currently manages PMSE spectrum assignments for Ofcom in the UHF spectrum. Channels 21–68 (with the exception of Channels 36 and 38) are used on an interleaved basis with DTT for services such as radio microphones, in-ear monitors, ‘cue,’ and ‘talkback’. Channel 69 is available nationally for these services. Much of the PMSE equipment in this band is designed for Channel 69, as this channel is available nationwide. Much of this equipment also tunes over Channels 67 and 68.

During the interviews we encountered significant interest from existing users in retaining use of these channels. Stakeholders stated that the production and show industry would need to revert to wired equipment if digital dividend spectrum were not available. This would represent a significant step backwards in terms of the quality of show that could be offered. In addition, if fewer channels were available for PMSE, large productions might not be able to have the number of radio microphones, IEM and talkback units that they currently enjoy, and in congested areas there might not be enough PMSE capacity to meet the needs of all users.

Stakeholders stated that these services (radio microphones, IEM, etc.) cannot be used in other frequency bands: higher bands are not possible as they would create significant health and safety issues, whilst at lower frequencies the required bandwidth is not available.

Spectrum requirements

The PMSE community would like to continue to interleave with DTT in either the retained or released spectrum (if DTT gets access to the released spectrum). It may also be possible

for PMSE to interleave with other users but sharing with ‘high-density’ systems (e.g., cellular) is not considered feasible.

2.2.5 Cellular/BWA services

Interest in the spectrum

We detected some interest from existing cellular operators in using this spectrum to roll out 3G services to rural areas and for improved in-building coverage. This is because the UHF band has more favourable propagation characteristics than other existing cellular spectrum. However, it was suggested that the level of interest is somewhat dependent on this band being harmonised across Europe (or across other major markets) as this will affect equipment/handset availability and cost. Furthermore, the availability of current 2G spectrum holdings for 3G would affect the value that an operator would place on digital dividend spectrum. If an operator has access to 900MHz spectrum for 3G, the value it would place on digital dividend spectrum would be reduced.

We also encountered interested from existing/potential BWA operators in this spectrum’s offering a ‘mobile broadband’ service. The propagation characteristics of digital dividend spectrum would enable operators to deploy in more rural areas than other, higher frequency BWA holdings (3.5GHz and potentially 2.6GHz). Technologies that might be used to deploy such services include WiMAX revision e and UMTS TDD.

Spectrum requirements

Cellular operators have a preference for paired 5MHz channels. Operators identified a couple of potential pairings that may become harmonised with other markets:

- Channels 63/64 paired with 68/69 (a US allocation)
- Channels 33/34 (and some of 35) paired with 39/40 (UMTS 500).

BWA technologies are becoming more flexible than cellular in terms of channel size, however, multiples of 5 or 10MHz are preferable. BWA would not require paired spectrum.

2.2.6 PMR/PAMR

Interest in the spectrum

There is general demand for spectrum for digital PMR/PAMR but not specifically for digital dividend spectrum. However, there is interest in digital dividend spectrum to offer video services for the emergency services. This would be based on DVB-H technology.

Spectrum requirements

Such a video service would require a single 8MHz channel. It is possible that this service could interleave with another service (e.g., DTT).

2.2.7 Licence-exempt services

Interest in the spectrum

The spectrum could be used to offer a number of licence-exempt services. These include:

- wireless ‘last-mile’ applications (including in-house entertainment networks)
- safety-of-life applications
- transport congestion alleviation
- automated buildings
- RFIDs
- medical sensors.

However, after consideration of the arguments brought forward by stakeholders we believe that there are mainly two areas in which licence-exempt applications could benefit from digital dividend spectrum, namely *fixed broadband wireless access*, particularly for the last mile to customers in rural areas, and *wireless home entertainment and personal area networks*, for in-home distribution of content. These are the services that could most benefit from digital dividend spectrum because:

- they have particular potential as mass-market applications, and thus may generate high aggregate value across consumers

- they were identified by some stakeholders as potential applications for this spectrum
- unlike most other licence-exempt uses, there are some advantages from deploying these services using digital dividend spectrum rather than higher frequency spectrum.

For a more detailed consideration of these two applications please refer to Annex B.

Spectrum requirements

Stakeholders suggested that three 8 MHz channels should be cleared nationally for licence-exempt use, with a power limit of around 100mW. However, the possibility of using interleaved spectrum was raised. It also may be possible for licence-exempt services to use ‘detect and avoid’ techniques to share frequencies with other uses.

3 Compatibility considerations

This chapter summarises the technical compatibility issues that are likely to arise between alternative potential uses of digital dividend spectrum (as identified from our stakeholder interviews discussed in the previous chapter) and also with other uses of the UHF spectrum band in the UK and overseas. The summary in this chapter is supported by a more extensive paper (Annex A) discussing the engineering parameters that underlie the technical analysis and presenting the results in further detail.

3.1 Introduction

The potential uses of the digital dividend spectrum are very varied in respect of their spectrum requirements, nature of the transmissions (e.g. power levels, one-way/two-way) and the interference levels that are tolerated. Additionally, there is potential for uses of the digital dividend spectrum to cause harmful interference to other services such as the six 'base' DTT multiplexes⁶ which will be using UHF spectrum during or following the DSO. International usage of UHF spectrum also places constraints on the use of the spectrum. This is summarised in Exhibit 3.1 below.

⁶

Following digital switchover, a total of six DTT multiplexes will be available in the UK. We call these the six 'base' multiplexes to distinguish them from any additional multiplexes that may be deployed using the digital dividend spectrum.

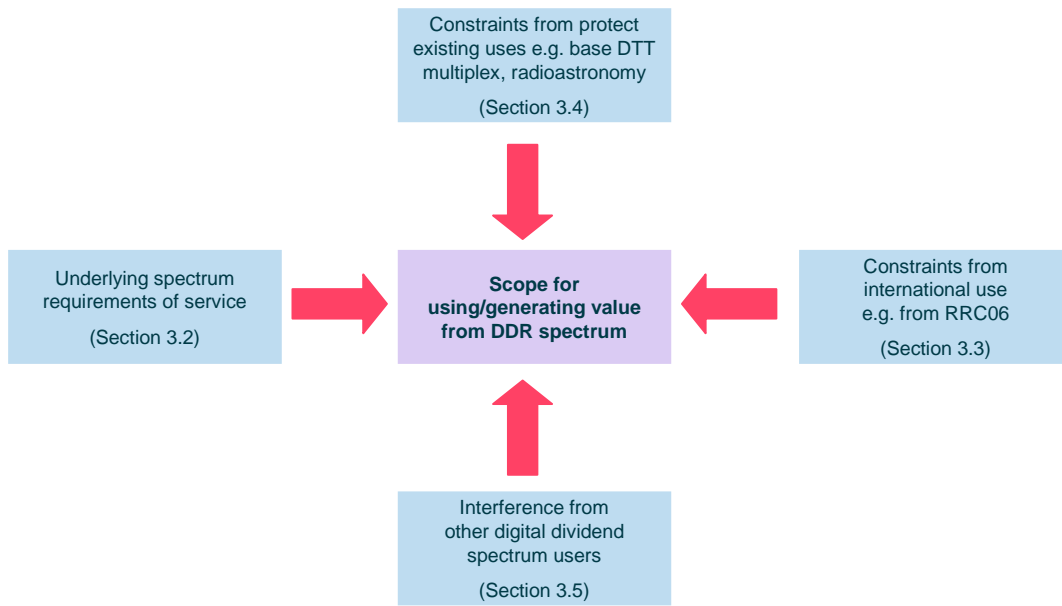


Exhibit 3.1: Constraints on use of digital dividend spectrum

In this chapter we summarise the results of our high-level assessment of the compatibility of alternative uses of the spectrum by considering the various interference modes that may arise between different uses, including:

- *co-channel interference* – typically between uses operating in different geographical areas
- *adjacent channel interference* – typically between uses that are operating in the same area but in adjacent frequency channels
- *other interference effects* – typically arising in the immediate vicinity of transmitter sites.

The remainder of this chapter is structured as follows:

- Section 3.2 provides an overview of the spectrum requirements associated with alternative uses of the spectrum
- Section 3.3 discusses the constraints on the use of digital dividend spectrum arising from international agreements – in particular the outcome of the RRC-06 conference
- Section 3.4 discusses the constraints on the use of digital dividend spectrum resulting from the need to protect other services using the band (e.g. the six base DTT multiplexes, radioastronomy in Channel 38) from interference

- Section 3.5 discusses the adjacent channel and other interference considerations arising from the alternative uses of digital dividend spectrum
- Section 3.6 summarises the key technology compatibility issues that we have identified from our analysis.

In this section we provide an overview of the results of our analysis: for further details of the assumptions and methodologies used, the reader is advised to consult Annex A, which provides additional information. It is important that the reader recognises the assumptions that underlie the analysis presented in this section (e.g. transmitted power levels, assumed antenna heights/gains, etc.) before drawing any firm conclusions from the graphics and so on presented here.

In the following, we provide illustrations of the different interference effects on specific channels of the digital dividend spectrum, and in doing so we have chosen channels which provide a good illustration of the impact of the particular interference effect across all released spectrum; Channels 31 and 64 are used to show this. Please note, however, that the interference environment for Channels 36, 68 and 69 differs from this, since:

- international usage of Channel 36 is currently constrained because of the need to provide sufficient protection for UK aeronautical radar use – please note that the interference constraints for Channel 36 as illustrated in Annex A may therefore not be fully representative of the future interference environment as this will depend on the nature of any agreements reached between the UK and its neighbours for use of Channel 36 for services different from the current allocation in the UK
- Channels 68 and 69 are used in France for military purposes rather than broadcast TV.

Illustrations of the interference constraints associated with Channels 36, 68 and 69 can be found in Annex A.

3.2 Spectrum requirements

Based on our stakeholder interviews, we have summarised the spectrum requirements of the main potential uses of digital dividend spectrum in Exhibit 3.2 below.

Use	Preferred channel package	Directionality	Geography	Potential no of users	Other issues
DTT	Multiplex derived from multiple 8MHz channels	Downlink only	National (across multiple channels)	Up to 3	No of 8MHz channels required varies with desired coverage/ capacity
Local TV	Single 8MHz channel	Downlink only	Local area (e.g. major city)	Numerous – across different areas of country	
Mobile multimedia	1.7MHz to 8MHz channels	Downlink only	National channel preferred – multiple channels possible	2 or 3?	
Cellular (FDD)	Paired 5MHz channel, specific frequency separation may be required	Downlink and uplink (pair of channels required)	National channel	Up to 5?	Interest in spectrum is subject to it being identified as a harmonised band
Broadband wireless (TDD)	3.5MHz to 40MHz(?) channel	Downlink and uplink (single channel with TDD)	National channel	2 or 3?	
PMSE	Various – main use is of 200kHz channels	Use is primarily one way	Primarily localised (low power) use	Numerous	Many other types of use

Exhibit 3.2: *Spectrum requirements of potential uses of digital dividend spectrum as identified through stakeholder interviews*

In addition to the direct stakeholder input, we have considered other potential technology configurations that could be deployed to meet the uses identified by stakeholders. Combining these, we can summarise the overall demand as follows:

- *DTT users* (excluding local TV) require unpaired 8MHz channels on a national basis – utilising multiple channels across the released digital dividend spectrum frequency range and across the UK, in order to benefit from frequency assignments made at the RRC-06 conference (this is discussed further in Section 3.3 below).
- *Local TV users* require a single 8MHz channel in a number of local areas (e.g. major cities).

- *Mobile multimedia users* require one or more unpaired 1.7MHz to 8MHz channels on a national basis. If it is not possible to obtain a single channel on a national basis, use of multiple channels to support a multi-frequency network (MFN) would be acceptable. The use of 3–8 channels for an MFN might also be required in order to provide different content in different regions of the UK. The use of an MFN rather than a single frequency network (SFN) might also simplify network design, by mitigating self-interference effects.
- *Cellular users* require paired 5MHz channels on a national basis to support both downlink and uplink transmissions – stakeholders have indicated that the spectrum must, however, be harmonised on an international basis, which could include the specification of particular channel combinations (or a specific frequency separation between uplink and downlink channels) as for existing cellular bands. The possibility of pairing with frequencies outside the UHF broadcast spectrum might also be of interest, as may be the use of unpaired channels for time division duplex (TDD) technologies.
- *Broadband wireless users* require unpaired spectrum ranging from 3.5MHz to up to approx 40MHz in bandwidth on a national basis – each channel would be used to support both downlink and uplink transmissions on a TDD basis. There may also be interest in paired spectrum for frequency division duplex (FDD) technologies.
- *PMSE users* have a wide range of channelisation requirements. The most common use is for radio microphones, typically with a 200kHz bandwidth.

Please note that the above list of uses (and technologies) should not be regarded as a complete list – there are other potential uses of the spectrum, but within the timescales available for the study we have had to focus on those uses which stakeholders have identified to the project team during our stakeholder interviews.

Different types of users have specific requirements as regards the frequencies they seek from the available digital dividend spectrum:

- *DTT users* may seek the use of specific channels in specific locations (e.g. Channels 33 and 37 at Crystal Palace) as a result of constraints arising from international use of the

spectrum, and a desire to avoid the need for any households to (i) deploy a new wideband aerial and/or (ii) deploy a second aerial (see Section 3.3 for further details of these issues).

- *Mobile multimedia users* seek spectrum in the lower part of the frequency band (below 750MHz) in order to enable mobile broadcast technologies to simultaneously operate in cellular phones that use the 900MHz GSM band (GSM transmission in the handset would create unwanted energy that would fall in the mobile multimedia receiver channel).
- *Cellular users* seek spectrum which has been harmonised on an international basis. The UMTS Forum has recently indicated its interest in WRC-07 making the 470–600MHz band available for cellular services (GSM and UMTS) across Europe.
- *Broadband wireless users* may also require spectrum in the lower part of the frequency band (below 750MHz) if it is anticipated that BWA technologies will be integrated into user terminals which could also use the GSM 900MHz band simultaneously (for example, to facilitate seamless roaming between a BWA network and a GSM network deployed in the 900MHz band).
- *PMSE users* have a wide range of existing equipment which operates in the existing spectrum, including (but not limited to) Channels 67 to 69. Extensive use is made of Channel 69 in particular as the licensing regime allows equipment to be used anywhere in the country. Such users would therefore prefer to continue to be able to use these channels.

In summary, it can be seen there is a wide range of demand for digital dividend spectrum and that certain uses have specific requirements for individual frequency channels or ranges of channels.

Please note that in view of the wide variety of combinations of cellular and BWA services using paired (FDD) and unpaired (TDD) technologies, for the purpose of our technical analysis we have modelled an FDD cellular service and a TDD BWA service. The key findings in relation to the FDD and TDD technologies modelled should apply across both cellular and BWA services.

3.3 Constraints on use of digital dividend spectrum arising from international agreements

The agreements reached at the RRC-06 conference place some limitations on the use that can be made of digital dividend spectrum. Of particular note are the following:

- RRC-06 provides the UK with rights to make DTT transmissions at high power levels using individual channels at specific sites in the UK (typically two channels within the digital dividend spectrum at each main broadcast site). It also offers the UK protection from harmful interference to reception of those DTT transmissions.
- RRC-06 provides similar rights to other countries: that is, the UK cannot cause harmful interference to other countries' use of spectrum for any transmissions that have been included in the RRC-06 plan.
- Individual countries can enter into bilateral agreements which supplement or supersede the rights and obligations included in RRC-06.
- RRC-06 does not constrain UK use of digital dividend spectrum to be for DTT as per the transmitter plan included in the RRC-06 agreement. However, UK use must not cause more interference than the DTT transmitter plan would cause, and likewise the UK cannot demand any more interference protection than was agreed in the RRC-06 plan.

Implications for use of digital dividend spectrum for DTT

Our analysis suggests that the main impact of these constraints will be on potential use of digital dividend spectrum for DTT services. As indicated in Section 3.2, stakeholders with an interest in deploying a DTT network have indicated to us that they wish to benefit from the transmission rights negotiated at RRC-06 since this will enable them to offer DTT coverage using high-power broadcast sites, without having to renegotiate with the UK's neighbours.

As an illustration of the constraints that the RRC-06 places on UK use of digital dividend spectrum for DTT, Exhibit 3.3 below shows the main DTT transmitter sites where Channels 31 and 64 could not be used (shown as red diamonds) due to unacceptable levels of interference being caused to the UK's neighbours.

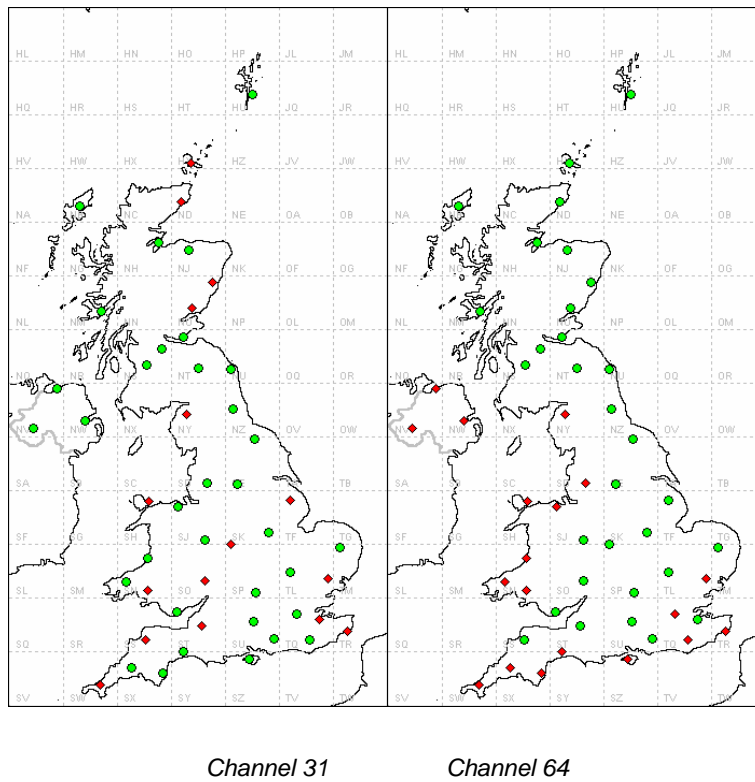


Exhibit 3.3:
Illustration of main DTT transmitter sites (shown as red diamonds) which could not be deployed in Channels 31 and 64 due to causing harmful interference TO other countries
 [Source: Aegis]

Likewise, incoming interference from Continental use of the digital dividend spectrum may cause harmful interference to reception of DTT in the UK. Exhibit 3.4 again takes the example of Channels 31 and 64 and highlights (in red) those areas of the UK where DTT reception may be limited by Continental interference.

It should be noted that the highlighted areas only indicate regions in which interference *may* occur if the wanted DTT signal is locally weak. In practice, the transmitter network could be designed to provide sufficient signal (where possible, in light of the outgoing constraints noted above) to overcome such interference. Please note that in these plots, account is taken of the directivity of the receiving DTT antenna, which provides some rejection of interference arising from broadcast signals from other countries.

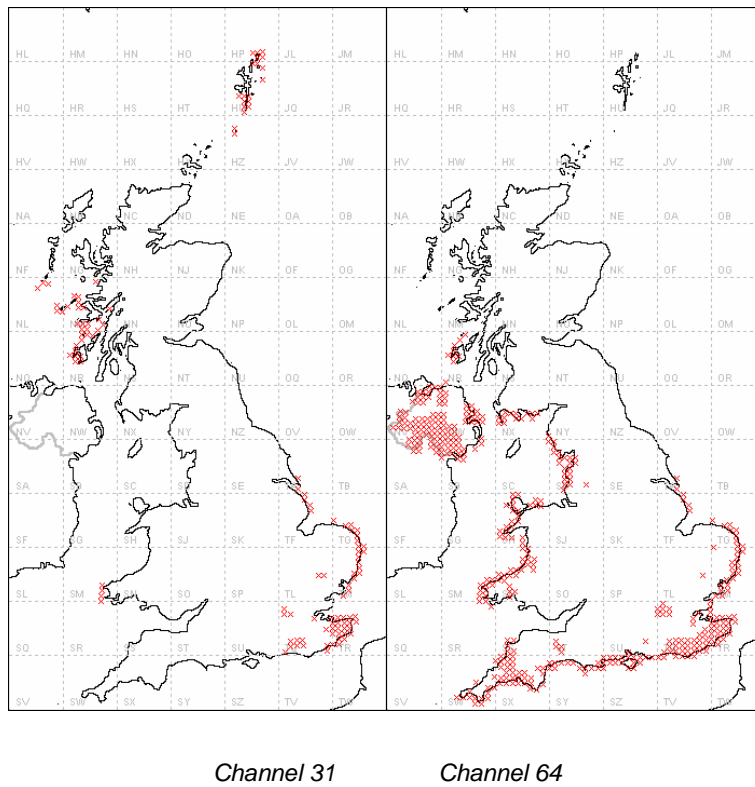


Exhibit 3.4:
Illustration of areas where UK DTT Channels 31 and 64 may be limited due to harmful interference FROM other countries
 [Source: Aegis]

The effects shown above will be similar, though different in detail, for the other digital dividend channels.

Please note that in Exhibit 3.4 the ‘gaps’ in the map shown for Channel 64 where reception is not harmed in some parts of Northern Ireland arise from the assumption that household antennas in these areas will be pointing towards existing transmitter sites and away from the Republic of Ireland.

The amount of digital dividend spectrum required by a potential DTT multiplex operator will depend upon the coverage level that the operator wishes to provide. The RRC-06 agreement includes transmission rights that would allow the UK to deploy two new DTT multiplexes – one with approximately 98.5% population coverage and another with approximately 90% population coverage. This configuration utilises 14 of the released channels (Channels 31–35, 37, 39–40 and 63–68) – virtually all of the released spectrum. The RRC-06 agreement is based on the use of each of these channels at specific locations (e.g. Channels 33 and 37 at Crystal Palace) and the channels available at individual sites

were designed to avoid households needing to deploy new wideband antennas or multiple antennas (see below for further discussion of these issues).

Potential users of DTT have indicated they would prefer to utilise the channel configurations agreed as part of RRC-06 as this provides a low-risk means of meeting their coverage objectives, since DTT multiplex operators will be able to automatically benefit from the high-power transmission rights (and interference protection rights) that the UK secured at RRC-06.

It may be possible to deploy DTT multiplexes using alternative spectrum configurations, but this is a more risky approach as it could require renegotiation of the rights and obligations agreed at RRC-06 to achieve maximum coverage. In Exhibit 3.5 below we estimate the minimum number of released digital dividend channels that would be required to provide multiplexes of differing coverage levels. Please note that these estimates should be taken to be purely indicative – detailed network design and transmitter channel planning will need to be developed in order to validate these figures. In making these estimates, it is also assumed that no re-negotiation of the UK rights under RRC-06 has taken place. If appropriate bi-lateral agreements with neighbouring countries can be reached, the number of channels required might be reduced.

<i>Population coverage (%) of one high-capacity DTT multiplex</i>	<i>Estimated number of digital dividend 8MHz channels required</i>
60%	2
70%	3
80%	4
90%	6
98.5%	10

Note that these figures are based on RRC-06

Exhibit 3.5:
Illustration of number of digital dividend channels required for DTT multiplex coverage
 [Source: Aegis]

It is important to note that international use of the band means that DTT multiplex operators will not be able to utilise just any combination of released channels to achieve the coverage levels shown in the exhibit. In particular, as indicated in the interference charts shown above, certain channels cannot be used in specific locations for high-power transmissions due to the potential harmful interference being caused to other international

users of the spectrum. There are also two further key considerations which relate to the receiving antennas used by most UK households:

- If the transmitter used for any new DTT multiplexes is located on a different site from those broadcasting the six base DTT multiplexes, e.g. in order to reduce the number of digital dividend channels required to achieve a certain population coverage, this could require the deployment of a second household antenna to receive the multiplex signals, in view of the directionality of the existing antennas.
- Many of the existing household antennas are not designed to operate over the whole of the 470–960MHz band, but only over a smaller subset of frequencies. The frequency planning for the six base DTT multiplexes has been designed to ensure that all broadcasts for reception in a given location fall within the same ‘channel group’. If frequencies outside the channel group were to be used for the new DTT multiplexes at various locations, some households wishing to receive the new services would need to upgrade to new wideband antennas.

In view of these further considerations, the demand for digital dividend spectrum for DTT is likely to be for specific combinations of channels. Examples of potential channel configurations are shown in Exhibit 3.6. Again please note that these possible configurations are illustrative – detailed network design frequency planning will be required to validate these estimates.

<i>Population coverage (%) of one high-capacity DTT multiplex</i>	<i>Estimate of potential released channels required to minimise need for wideband or second antenna and ease co-ordination</i>
60%	Channels 33 and 64
70%	Channels 31, 33 and 64
80%	Channels 31, 33 and 64-65
90%	Channels 31-34 and 64-65
98.5%	Channels 31-34, 37, 39 and 63-66

Exhibit 3.6:
Illustration of specific digital dividend channels required for DTT multiplex coverage
[Source: Aegis]

It should be emphasised that, with the higher-coverage options, not all channels will be used in all areas: a significant ‘interleaved’ resource will remain. Thus, even though access to more than 10 channels might be needed to achieve coverage of around 98.5%, the same

channels might simultaneously be used to provide, for example, a second DTT multiplex, albeit with lower population coverage.

Implications for use of digital dividend spectrum for mobile multimedia

The impact of RRC-06 constraints on the use of digital dividend spectrum for mobile multimedia services depends on the network topology that is to be deployed. For a high-power network similar to broadcast DTT networks, the constraints arising from the need to protect Continental DTT transmissions will be similar to those for DTT, as shown in Exhibit 3.3 above. It is possible that the constraints may be lower than those for DTT, through the use of more robust modulation schemes for mobile multimedia services.

From our stakeholder interviews, we understand that most organisations proposing to deploy mobile multimedia services are envisaging using a dense network of low-power transmitters more similar to a cellular base station network than a high-power broadcast DTT network. On this basis we have analysed the RRC-06 restrictions on a DVB-H network (see Section 3 of Annex A for details of the specific assumptions we have made).

For such networks, the interference caused by use of the band by Continental DTT will be lower, as a consequence of the higher field strength of the mobile multimedia network arising from the dense network of transmitters.

Exhibit 3.7 below highlights (in red) those areas where DVB-H transmitters could not be deployed in Channels 31 and 64 due to the risk of causing harmful interference to Continental and Irish users.

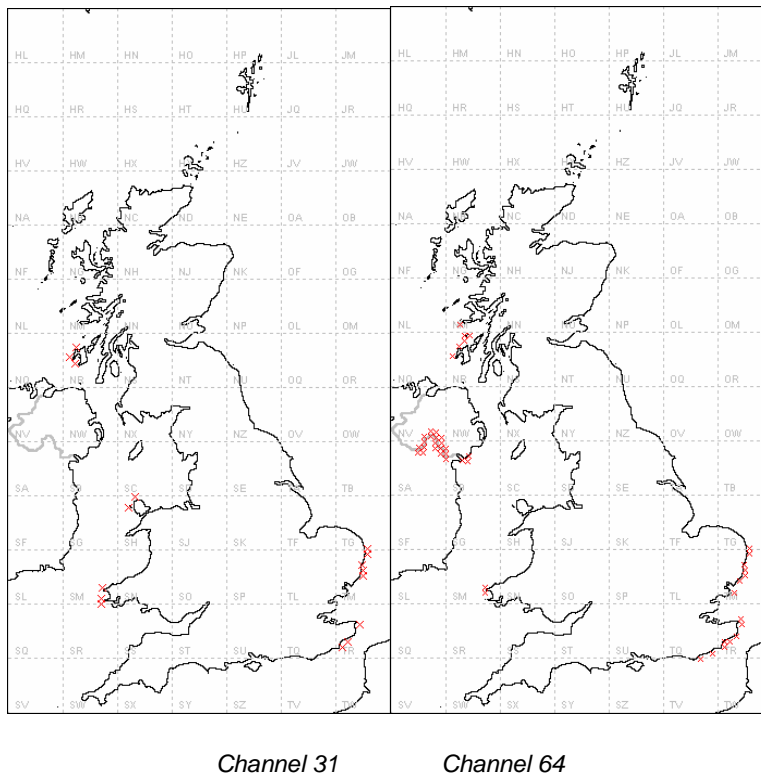


Exhibit 3.7:
Illustration of locations where DVB-H transmitters (medium power, dense network configuration) could not be deployed in Channels 31 and 64 due to causing harmful interference TO other countries
 [Source: Aegis]

Exhibit 3.8 below highlights (in red) those areas where DVB-H reception may be limited as a consequence of interference from Continental use of Channels 31 and 64.

As before, these illustrations are for Channels 31 and 64, though similar results are applicable for the other released channels.

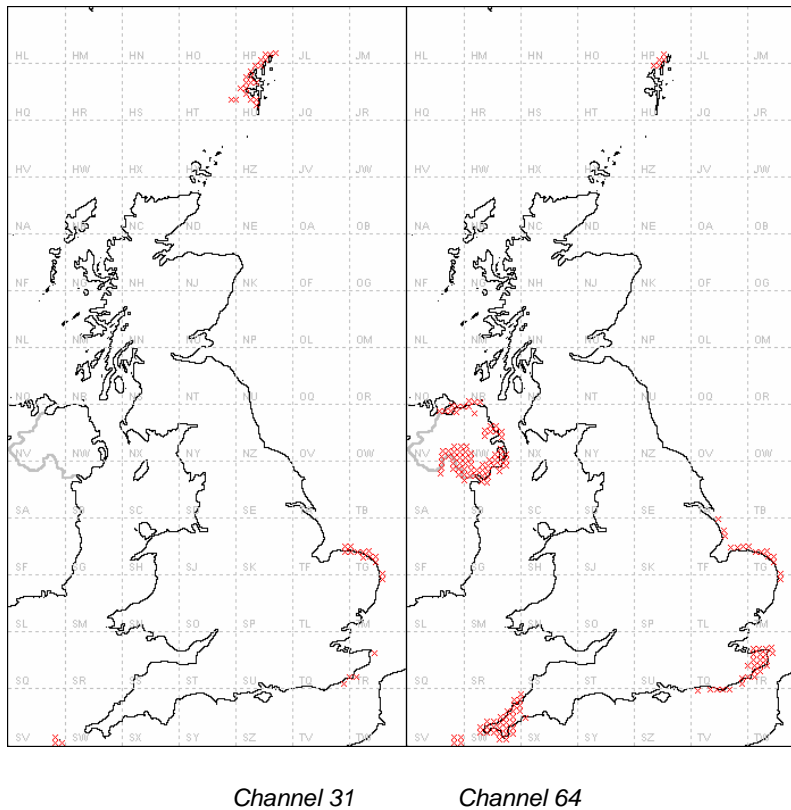


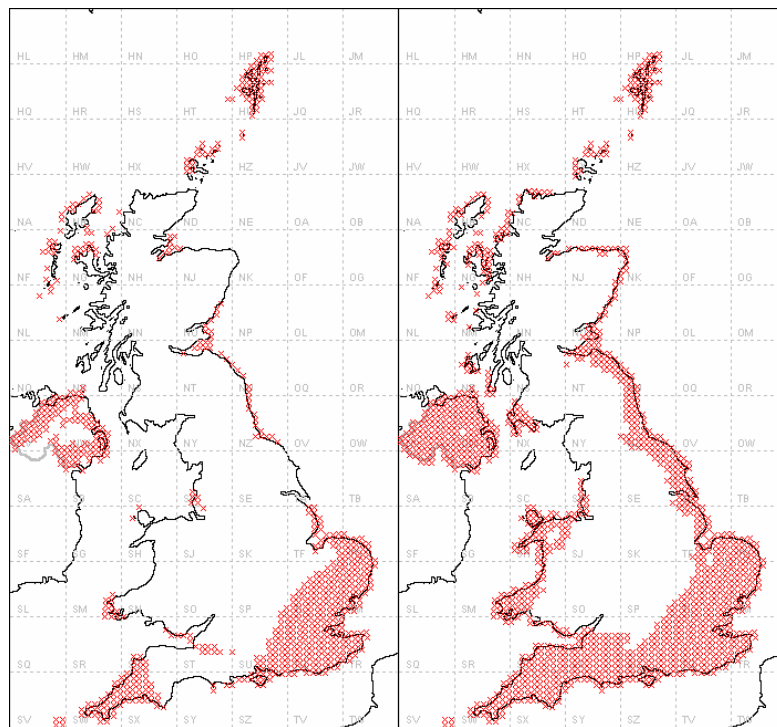
Exhibit 3.8:
Illustration of areas where DVB-H reception (medium power, dense network configuration) in Channels 31 and 64 may be limited due to harmful interference FROM other countries
 [Source: Aegis]

Implications for use of digital dividend spectrum for services with a mobile uplink component (e.g. cellular/BWA)

The uplink component of mobile services is generally highly vulnerable to interference, due to the low signal strengths involved. Interference from Continental use of digital dividend spectrum could therefore have a significant impact. In particular, tropospheric ducting effects, which only occur for short periods of time, could be significant. As an illustration of these effects, Exhibit 3.9 below shows that for a small proportion (1%) of time harmful interference from Continental DTT transmitters can affect cellular and BWA service uplinks using Channel 65 across considerable areas of the South East of England (areas shown in blue are prone to harmful interference). Similarly, Exhibit 3.10 below shows the areas in which cellular (UMTS) base station reception (uplink) in Channels 31 and 64 may suffer harmful interference from Continental use for 1% of the time.



Exhibit 3.9: Illustration of interference contour from Continental DTT transmitters on Channel 65 for 50% of time (left) and 1% of time (right) [Source: Aegis]



Channel 31

Channel 64

Exhibit 3.10: Illustration of areas where cellular base station reception in Channels 31 and 64 may be limited due to harmful interference from other countries for 1% of time [Source: Aegis]

It should be noted that the plots above represent a worst-case situation, with a stringent receiver protection requirement, and no assumption of protection due to antenna directivity. In practice, many base station antennas will offer significant rejection of such incoming interference.

For the *downlink* component of cellular and BWA services, interference effects are expected to be similar to those for mobile multimedia (DVB-H) as shown in Exhibit 3.7 and Exhibit 3.8 above.

Implications for use of digital dividend spectrum for PMSE

For the most common PMSE application in this band (radio microphones), international interference constraints should be minimal. The transmitter power of radio microphones is too low to cause any outgoing interference, while the receivers have low-gain antennas and are generally sufficiently well screened, so that incoming interference will not be troublesome. There will be occasional exceptions in coastal areas during abnormal propagation conditions, and at land border areas in Northern Ireland.

3.4 Constraints on use of digital dividend spectrum arising from protection of planned DTT and existing services

The use of the 470–862MHz band for planned services also places constraints on the use of digital dividend spectrum. Whilst the main planned use will be for the six base DTT multiplexes, consideration must also be given to other existing uses, including Channel 38 for the radio astronomy service, and users in frequency bands adjacent to the 470–860MHz band.

3.4.1 Protection of DTT services in the same channel (co-channel interference)

The scope for use of interleaved spectrum for new services is constrained by the need to protect the six base DTT multiplexes. A summary of the geographic separation that might be required is presented in Exhibit 3.11 below. In general it can be seen that the required separation varies significantly between the different potential uses of the digital dividend

spectrum. Please refer to Annex A for details of the assumptions that underlie the analysis presented below.

<i>Transmitting service</i>	<i>Receiving service</i>	<i>Required geographic separation</i>
DTT	DTT	Typically 130km separation required between transmitters to minimise interference. 30km separation would be required from a lower-power local TV DTT transmitter to the edge of the base multiplex coverage area.
Mobile multimedia	DTT	18km separation required between mobile multimedia transmitter and edge of DTT coverage area.
Wireless broadband (TDD)	DTT	18km separation required between wireless broadband base station and edge of DTT coverage area. 650m separation required between transmitting user terminal and DTT receiver on edge of DTT coverage area.
Cellular mobile (FDD)	DTT	18km separation required between cellular and base station and edge of DTT coverage area. 650m separation required between transmitting mobile terminal and DTT receiver on edge of DTT coverage area.
PMSE	DTT	440m separation required between PMSE low-power transmitter and DTT receiver on edge of DTT coverage area.

Exhibit 3.11: *Geographic separation required to protect the six base DTT multiplexes from co-channel interference caused by other uses of the spectrum [Source: Aegis]*

DTT services are broadcast from high-power main stations and also from lower-power relays. These have differing impacts and hence separation requirements. We have considered both in examining the geographic separation required to prevent interference that DTT transmission might cause to new users of the spectrum. Our analysis is summarised in Exhibit 3.12. Again the reader is advised to refer to Annex A for further details of the assumptions that underlie this analysis.

<i>Transmitting service</i>	<i>Receiving service</i>	<i>Required geographic separation</i>
DTT	DTT	Typically 130km separation required between transmitters to minimise interference cases. 80km separation would be required from an existing high-power DTT transmitter to the edge of the local TV service area.
DTT	Mobile multimedia	Typically 35km separation from an existing high-power DTT transmitter to a mobile multimedia terminal.
DTT	Wireless broadband (TDD)	Typically 180km separation from an existing high-power DTT transmitter to a wireless broadband base station and typically 70km separation to a receiving broadband wireless user terminal.
DTT	Cellular mobile (FDD)	Typically 180km separation from an existing high-power DTT transmitter to a cellular base station and typically 70km separation to a receiving cellular mobile user terminal.
DTT	PMSE	Typically 60km separation from an existing high-power DTT transmitter and low power PMSE equipment.

Exhibit 3.12: *Geographic separation required to protect other users of the spectrum from co-channel interference caused by the six base DTT multiplexes [Source: Aegis]*

3.4.2 Protection of DTT services in other channels

DTT receivers (e.g. set-top boxes) are prone to interference from other channels. Exhibit 3.13 illustrates the typical sensitivity of DTT receivers to signals in adjacent and other channels. In addition to the immediately adjacent channel ($n \pm 1$), the so-called ‘image channel’ ($n + 9$) is also susceptible to interference from transmissions in this channel (for further details of this effect please see Section 1.2.3 of Annex A).

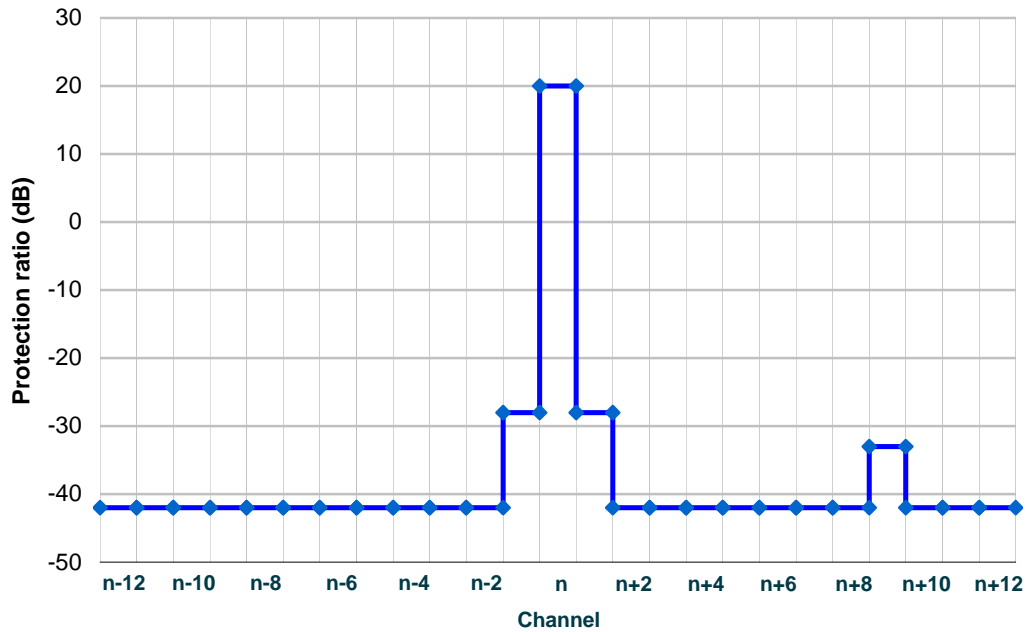


Exhibit 3.13: Sensitivity of DTT receivers to interference from signals in adjacent channels ($n \pm 1$) and the image channel ($n + 9$) [Source: Aegis]

As shown in Exhibit 3.14, in addition to the use of Channels 31, 40 and 63 of the released spectrum being affected by the need to avoid harmful adjacent channel ($n \pm 1$) interference being caused to DTT reception, the use of Channels 31–37, 39 and 63–68 is also affected by the image channel ($n + 9$) susceptibility of DTT receivers.

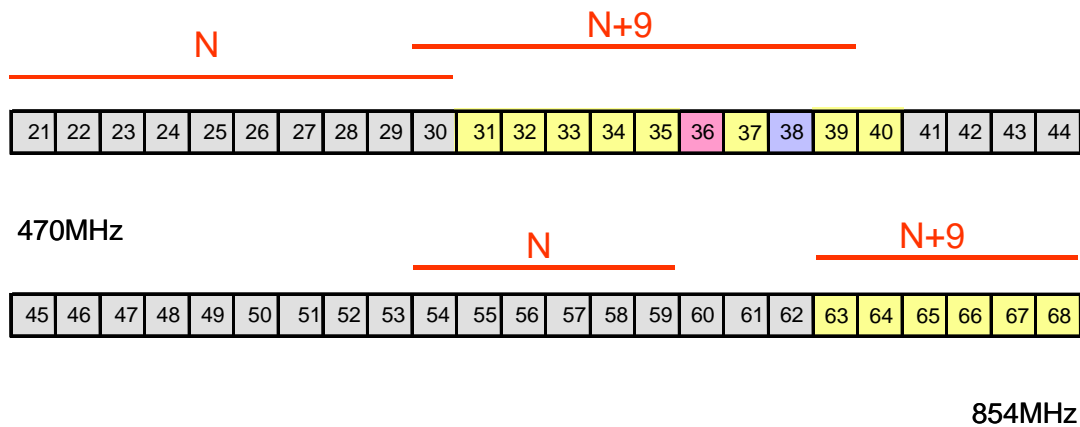


Exhibit 3.14: Released channels affected by image channel (n+9) susceptibility of DTT receivers [Source: Aegis]

This vulnerability of the DTT receivers means that, for a particular channel, if a transmitter site (for DTT or any other service) were deployed in an adjacent channel ($n \pm 1$) or image channel ($n + 9$), there may be an area around the transmitter site where that DTT channel could not be received. This effect, illustrated in Exhibit 3.15 below, is known as ‘hole-punching’ because the interfering service punches holes in the service area of another user in the immediate vicinity of the transmitter. The hole-punching problem arising from image channel interference will be far less than that arising from adjacent channel interference.

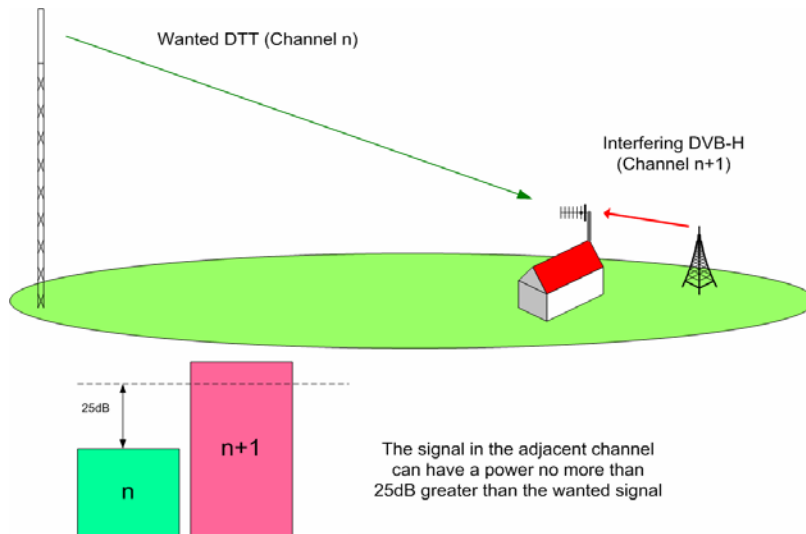
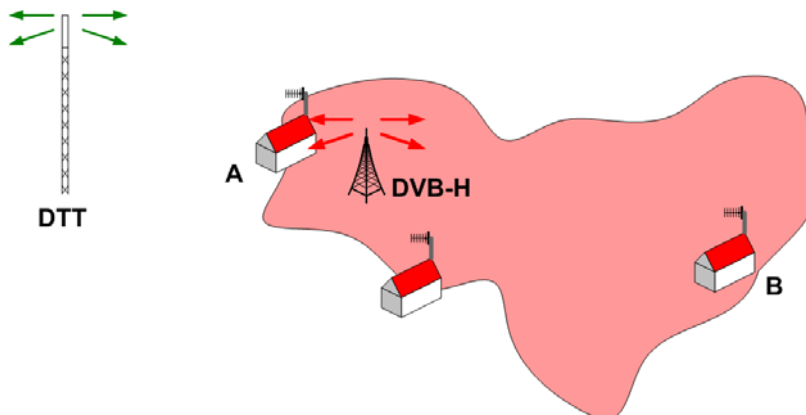


Exhibit 3.15:
Illustration of hole punching effect
 [Source: Aegis]

The area within which 'hole-punching' occurs will be irregular. Though household 'A' is closer to the interfering transmitter, the receive aerial offers discrimination against the interfering signal. The aerial at 'B', however, is aligned with the source of interference.

Local propagation effects will also have a significant effect on the area affected



Hole-punching effects can be mitigated using a number of approaches, including (but not limited to) the following:

- Providing sufficient frequency separation (often referred to as a guard band) between the different interfering transmissions.
- For new DTT transmissions, such hole-punching issues may not arise if any new DTT transmitters can be co-located with existing DTT transmitters, so that the interfering

signals in the adjacent channels ($n \pm 1$) or image channel ($n + 9$) are not strong enough to cause harmful interference to the reception of the wanted channel.

- For other services with fixed transmitter sites (e.g. mobile multimedia base stations), a filler DTT station co-located with the interfering transmitter may be sufficient. If an off-air signal can be used (and then rebroadcast), we estimate that such a filler station could cost around GBP15 000 to GBP17 000 (on top of the site costs which would already be incurred). Such a solution might also be appropriate for a new DTT transmitter that was not co-located with existing DTT transmitters.
- For services with moving transmitters (e.g. the uplink component of cellular or mobile BWA services), solutions involving retransmission of the original DTT signal are unlikely to be practical. Power limitations on such uplink transmissions would reduce the number of instances of interference that occurred, but frequency separation may be required to bring the number down to acceptable levels.
- For PMSE, the transmitted signals will generally be of sufficiently low power that no interference will be caused.

Determining the likelihood of hole-punching due to interference from adjacent ($n \pm 1$) or image ($n + 9$) channels involves complex statistical considerations, in which the relative distributions of transmitters and receivers need to be accounted for, and the spread in performance of receivers, transmitters, antennas and feeders considered. Where problems occur, these are likely to be in areas where DTT signal levels are marginal: for a densely deployed network (such as one for mobile multimedia), only a proportion of the transmitters are likely to be affected. Finally it should be noted that interference arising from usage of the image channel will always be less severe than that caused by usage in adjacent channels. Some estimates are given in Annex A.

3.4.3 Protection of existing use of Channel 38 for radio astronomy

Channel 38 is expected to continue to be used by the radio astronomy service (in particular by the Jodrell Bank Observatory in Cheshire, but also at sites in Cambridge and Worcestershire). This places stringent constraints on the use of the adjacent channels

(Channels 37 and 39) – for example the existing analogue “Five” transmitter at Lichfield uses an expensive filter. The radio astronomy community also incurs significant costs in minimising the impact of interference from adjacent channels.

As an illustration of the constraints that might arise, Exhibit 3.16 below shows the area around Jodrell Bank in which a 10kW DTT transmitter operating in Channel 37 or Channel 39 might cause harmful interference to radio astronomical observations in Channel 38. Please note that such interference may be ameliorated by filtering, or by careful transmitter aerial design and choice of transmitter location. Further details are given in Section 8 of Annex A.

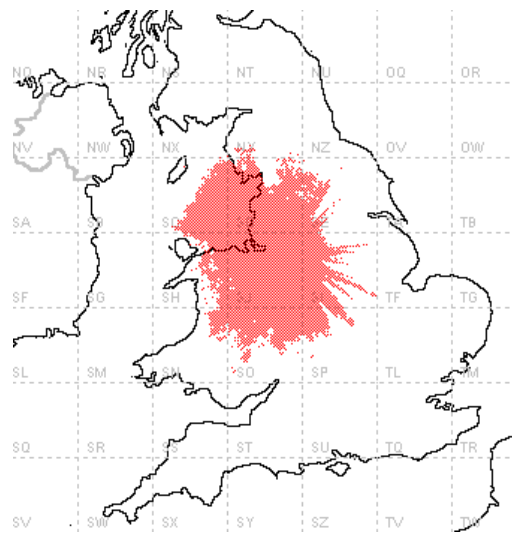


Exhibit 3.16:
Interference zone
around Jodrell
Bank for 10 kW
DTT transmitter
(‘critical’ mask with
no additional
filtering) [Source:
Aegis]

3.4.4 Protection of users in the 450-470MHz band

New services operating in Channel 21 on an interleaved basis with the six base DTT multiplexes may be subject to constraints to protect mobile services operating in the 450–470MHz band. For example, existing TV transmitters (analogue and DTT) operating in Channel 21 are required to operate with a more stringent emissions mask. Please see Section 2 of Annex A for further details.

3.4.5 Protection of users above 862 MHz

The 8MHz band immediately above Channel 69, from 862 to 870 MHz (sometimes referred to as ‘Channel 70’) is allocated in the UK for licence-exempt use by short-range devices including radio microphones, alarm systems and wireless headphones.

If high-power applications were to make use of Channel 69, they might cause adjacent channel ($n \pm 1$) interference to such devices. Such a use of Channel 69 is, however, unlikely to be possible owing to bilateral agreement to protect existing French military use of the channel.

The 870–872MHz band is allocated to the Ministry of Defence.

The spectrum at 872–876MHz is due to be released by Ofcom through an auction award process in 2007. We understand that use of the 872–876MHz band will be restricted to terminals with a maximum power (EIRP) of 2W, so interference to users of the digital dividend spectrum is unlikely. However, there is a possibility that very local interference might be caused if the interleaved spectrum in Channel 62 were to be used for a DTT multiplex, as a consequence of the image channel interference mechanism described above.

3.5 Adjacent channel interference between different uses of digital dividend spectrum

There are a wide range of adjacent channel ($n \pm 1$) interference effects that could occur from the alternative uses of digital dividend spectrum.⁷ A summary of these is presented in Exhibit 3.17 below, but the reader is advised to refer to Annex A for details of the individual interference mechanisms – in particular the assumptions relating to the transmission and reception requirements for each service which form the basis of our analysis.

⁷ Please note that co-channel interference issues would also arise if different services were to use the same channel in different areas of the UK. Section 7.1 of Annex D provides details of the geographic separation that would be required between the services in order to prevent harmful interference.

The main type of interference that is likely is hole-punching resulting from the transmitter of one user interfering with another user that is using an adjacent channel in the immediate vicinity of the transmitter. As indicated in Section 3.4, one potential solution is for transmitters (e.g. those of new DTT users) to be co-located. This solution is not always possible when different network architectures are involved (e.g. a very high-power low-density DTT network as against a dense network of DVB-H transmitters). The use of filler stations (as described in Section 3.4 above) is an alternative solution.

Exhibit 3.17: *Potential adjacent channel interference issues between services*

<i>Transmitting service</i>	<i>Receiving service</i>	<i>Principal interference issue(s) and potential remedy(ies)</i>
DTT	DTT	Hole-punching of service in adjacent channel in region surrounding high power broadcast transmitters. Co-locating of transmitters is the best solution, and likely to be sought due to receive aerial alignment issue.
DTT	Mobile multimedia	Hole-punching of service in adjacent channel in region surrounding transmitters. Co-ordination of sites (e.g. deployment of 'filler' stations) will reduce number of users affected.
DTT	Wireless broadband (TDD)	DTT transmissions could prevent reception of weak wireless broadband signals, effectively reducing the coverage area of a given BWA base station.
DTT	Cellular mobile (FDD)	DTT transmissions could prevent reception of weak mobile signals, effectively reducing the coverage area of a given cellular base station.
DTT	PMSE	Interference from DTT transmitters in the adjacent channel would effectively mean that there are areas in the vicinity of the DTT transmitter site in which PMSE cannot be reliably used (as is currently the case).
Mobile multimedia	DTT	Hole-punching of service in adjacent channel in region surrounding transmitters. Co-ordination of sites (e.g. deployment of filler stations) will reduce number of users affected.
Mobile multimedia	Mobile multimedia	Hole-punching of service in adjacent channel in region surrounding transmitters. Co-ordination of transmitter sites between users will reduce interference issues.
Mobile multimedia	Wireless broadband (TDD)	A mobile multimedia transmitter could prevent reception of weak wireless broadband signals, effectively reducing the coverage area of a given wireless broadband base station.
Mobile multimedia	Cellular mobile	A mobile multimedia transmitter could prevent reception of weak mobile signals thereby effectively reducing the coverage area of a

<i>Transmitting service</i>	<i>Receiving service</i>	<i>Principal interference issue(s) and potential remedy(ies)</i>
	(FDD)	given cellular base station.
Mobile multimedia	PMSE	Interference from mobile multimedia transmitters in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used.
Wireless broadband (TDD)	DTT	Transmitting broadband wireless terminals could interfere with DTT receivers tuned to adjacent channels in vicinity. Sufficient frequency separation between the services is likely to be required.
Wireless broadband (TDD)	Mobile multimedia	Transmitting broadband wireless terminals could interfere with mobile multimedia handsets receiving broadcasts in adjacent channels in vicinity of a wireless broadband terminal. Sufficient frequency separation between the services is likely to be required.
Wireless broadband (TDD)	Wireless broadband	Interference between base stations located in close proximity is the main interference concern. If TDD technologies are used, one base station could be transmitting at the same time as another is receiving – with the transmitting signal overwhelming a weaker received signal. Therefore extensive co-ordination of the services would be required (e.g. tight synchronisation of base station transmit/receive cycles).
Wireless broadband (TDD)	Cellular mobile (FDD)	Interference between base stations located in close proximity is the main interference concern. For example if the wireless broadband service uses TDD technology, the BWA base station could be transmitting at the same time as the cellular base station is receiving a weak signal from a mobile handset. Frequency separation between the services is likely to be required – extensive co-ordination of base station sites is unlikely to be sufficient.
Wireless broadband (TDD)	PMSE	Interference from BWA base stations in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used.
Cellular mobile (FDD)	DTT	Transmitting mobile cellular terminals or base stations could interfere with DTT receivers tuned to adjacent channels in vicinity. Sufficient frequency separation between the services is likely to be required.
Cellular mobile (FDD)	Mobile multimedia	Transmitting mobile cellular terminals could interfere with mobile multimedia handsets receiving broadcasts in adjacent channels in vicinity of cellular terminal. Sufficient frequency separation between the services is likely to be required.
Cellular mobile (FDD)	Wireless broadband (TDD)	Interference between base stations located in close proximity is the main interference concern. For example a cellular mobile base station could be transmitting at the same time as a wireless broadband base station is receiving a weak signal from a user terminal. Frequency separation between the services is likely to be required – extensive co-ordination of base station sites is unlikely to be sufficient.
Cellular mobile	Cellular mobile	Provided the adjacent channels are both used for either uplink or downlink services, there should not be any significant interference

<i>Transmitting service</i>	<i>Receiving service</i>	<i>Principal interference issue(s) and potential remedy(ies)</i>
(FDD)	(FDD)	issues.
Cellular mobile (FDD)	PMSE	Interference from cellular base stations in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used.
PMSE	DTT	Interference from DTT transmitters in the adjacent channel would effectively mean that there are areas in the vicinity of the DTT transmitter site in which PMSE cannot be reliably used. If PMSE were to be used in these areas, it might cause interference to reception of DTT signals.
PMSE	Mobile multimedia	Interference from mobile multimedia transmitters in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used. If PMSE were to be used in these areas, it could cause interference to reception of mobile multimedia signals.
PMSE	Wireless broadband (TDD)	Interference from wireless broadband base stations in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used. If PMSE were to be used in these areas, it could cause interference to reception of wireless broadband signals.
PMSE	Cellular mobile (FDD)	Interference from cellular base stations in the adjacent channel would effectively mean that there are areas around the transmitter site in which PMSE cannot be reliably used. If PMSE were to be used in these areas, it could cause interference to reception of cellular signals.
PMSE	PMSE	No major issues due to localised, low-power use.

Annex A provides further details of such interference mechanisms, including an illustration of the distances over which interference issues might arise (see Section 7.2 of the Annex). Please note that the distances indicated in Annex A relate to the worst-case mechanism for each pair of services, for a particular set of technical assumptions (e.g. technology deployed, power levels, antenna height/gain, etc.) which are also detailed in the Annex.

From the table above it can be seen that, overall, co-ordination between spectrum users is likely to be key to effectively utilising individual channels. If absolutely no co-ordination between spectrum users were to occur, then we estimate that frequency separation (guard bands) of between 5 and 16MHz are likely to be required both sides of a wanted transmission in order to provide sufficient protection. This is particularly likely to be the case where mobile transmitting devices (e.g. uplinks of cellular and BWA services) are

used, in order to prevent them from causing harmful interference to users in adjacent channels.

As discussed in Section 7.3 of Annex A, the determination of necessary frequency separation between two specific services requires detailed statistical modelling for well-defined scenarios. For illustrative purposes, Exhibit 3.18 presents the results of an indicative assessment of the distances over which harmful interference to a cellular base station (using IS-95 CDMA technologies) could arise from a DTT transmitter using an adjacent channel. This is shown for frequency separations of 0MHz, 1.25MHz and 2.5MHz.

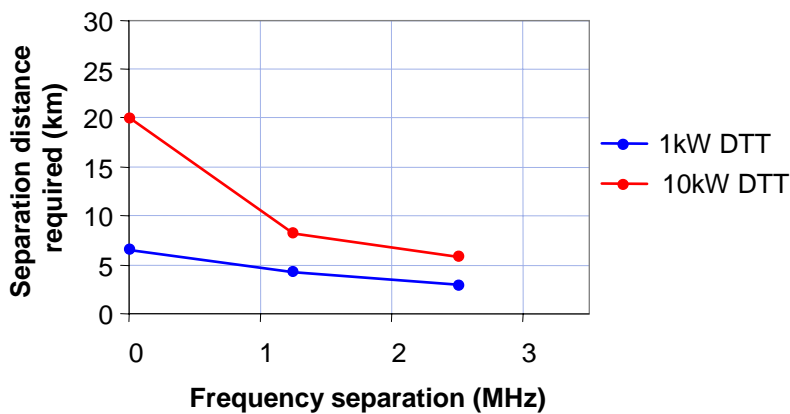


Exhibit 3.18:

Separation distance required to avoid DTT interference to CDMA base station, with differing transmitter power and frequency separation [Source: Aegis]

3.6 Summary of technology compatibility issues and implications for award process

The implications of the technology compatibility assessment for the award process are as follows:

- Spectrum users do not regard individual digital dividend channels as being alike. Certain users would prefer channels within a certain range, e.g. below 750MHz for mobile multimedia users, Channel 69 for PMSE users. Users may also prefer specific individual channels in specific locations, e.g. Channels 33 and 37 in the London/Crystal Palace area in order to take advantage of RRC-06 transmitter rights.

- Use of the digital dividend spectrum could lead to additional costs to protect the coverage of the six base DTT multiplexes – such costs could arise from deploying low-power DTT filler stations co-located with new transmitters. Such protection issues are likely to arise primarily in areas where new usage of the digital dividend spectrum is in an adjacent channel to one used by a base DTT multiplex. However, protection issues could also occur where a base DTT multiplex is using a channel nine channels below the new use, due to image channel interference. Usage of the interleaved spectrum for new services is possible, provided sufficient geographic separation is allowed between the new services and existing DTT coverage areas.
- Adjacent channel interference issues between new users of digital dividend spectrum could be significant. Ideally, the solution to these issues would rely on sufficient co-ordination between spectrum users to minimise hole-punching and other effects. If co-ordination does not occur, large frequency separations of 5–16MHz on both sides could be required between individual users in adjacent spectrum.
- Use of the digital dividend spectrum for mobile uplink services (e.g. cellular, BWA) will require sufficient frequency separation to protect users in adjacent channels from harmful interference. The susceptibility of DTT receivers to interference from transmissions in the image channel may mean that protecting reception of the six base DTT multiplexes may place significant constraints on the use of digital dividend spectrum for such uplink services.
- In respect of the implications for spectrum packaging, it is clear that packaging the released spectrum into multi-channel blocks would help to avoid interference issues. However, as indicated earlier, certain services have requirements for specific combinations of channels (e.g. DTT users may seek a mix of channels from both the lower and the upper blocks in order to benefit from RRC-06 transmission rights).

The interference constraints arising from international agreements and the use of the retained spectrum (e.g. for the six base DTT multiplexes) are by no means insignificant. However, potential users of digital dividend spectrum may be more concerned about the precise characteristics of the uses of the spectrum that may be made by other new users, and whether these other users will be willing to work together in co-ordinating deployment

to minimise interference to each other. This could have a significant impact on the use and value that a user can derive from the spectrum.

4 Total value from uses of spectrum

4.1 Introduction

The objective of this part of the project was to understand the ‘total value’ that each of the candidate uses of digital dividend spectrum could contribute to the economy and society.⁸ Specifically, we are interested in the incremental benefits that result from these services being provided using the digital dividend spectrum. If a service can only be provided using the digital dividend spectrum, total value would include all benefits associated with the service. However, where the service could be provided using an alternative delivery platform, such as another spectrum band or wireline solution, we are only concerned with the additional benefits from using digital dividend spectrum over-and-above those that would be realised from using the alternative platform.

We have assessed three measures of total value, which we discuss below.

- The **private value derived from use of the spectrum** captures the direct benefits to individuals from their own consumption of the service (i.e. the value consumers place on the service), less the costs of producing the service.⁹ In economic terms, this is equal to the sum of consumer and producer surplus.
- The **external value** captures any additional benefits to consumers or third parties not reflected in the value of the service to consumers. The total value therefore comprises the private value plus any external value. This broad definition captures all types of

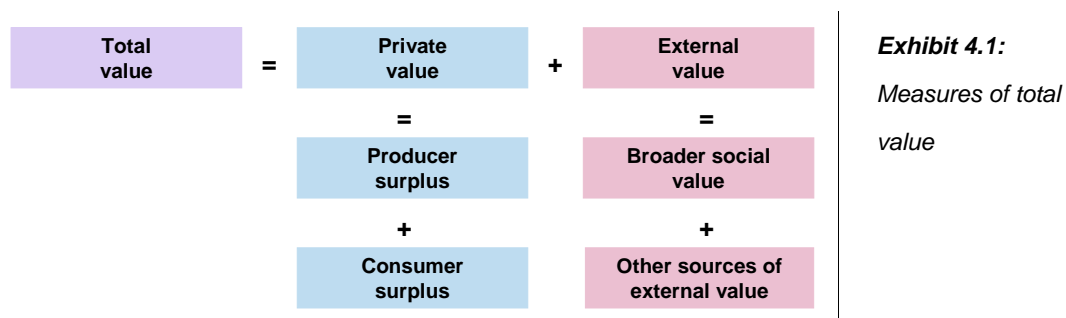
8 We use the term ‘total value’ throughout to refer to the sum of all benefits and costs associated with the allocation of spectrum to a particular service. In economic literature, this measure of overall value is often also referred to as ‘social value’.

9 To the extent that willingness to pay is expressed for the predicted level of take-up of services, it includes a portion of network benefits, namely those that would be internalised by the market. This would include network benefits anticipated by both consumers and service providers (e.g. economies of scale in handset or roaming benefits).

externalities,¹⁰ such as investment spillovers (knock-on benefits for other sectors of the economy), non-internalised network effects, and what we call ‘broader social values’ (referring to the value that the public derives from services because of their broader contribution to society). Externalities are not necessarily positive; we have also considered whether there may be any negative external effects, such as interference with existing services, or health concerns associated with transmission.

- The **willingness to pay for spectrum** by potential purchasers of the spectrum (e.g., network operators) is, in economic terms, a *proportion* of the producer surplus that would be derived from providing the service.

Exhibit 4.1 summarises the relationship between total value, private value and external value:



The purpose of analysing total value is to inform our understanding of how well a market mechanism could allocate spectrum to the services that can use the spectrum most efficiently and generate the greatest value for the economy and society. A key assumption underpinning the use of auctions for assigning spectrum licences is that bidders’ willingness to pay for spectrum will reflect the relative total value that candidate services will create. This is more likely to be the case if all bidders plan to deploy similar services and there are no significant competition concerns, but is less certain if bidders are competing for spectrum to supply different (non-substitutable) services.¹¹

10 Externalities are the unintended spillover effects of economic activity on third parties.

11 Borenstein (1988) highlights the potential for market mechanisms to result in inefficient allocation in the case that different firms, if assigned a licence, choose to enter different markets or to use different production technologies. See Borenstein, S, Quarterly Journal of Economics, Vol, 103(2), May 1988.

In the following sections, we summarise our assessment of the likely magnitude of both private and external benefits associated with each of our candidate services (Sections 4.2 and 4.3 respectively). Please note that, in Section 4.2, we present an overview of the underlying methodology used to develop our estimates of the private value of the candidate uses of the spectrum, together with a summary of the key findings. It would not be appropriate to publish full details of our assessment of organisations' willingness to pay for spectrum since (a) this utilises information which has been provided to us by stakeholders through the interviews and may therefore be confidential; and (b) publication of such information could unduly affect the outcome of a competitive award process. We are able to publish further details of the approach used to assess the external value which could arise from the alternative uses of digital dividend spectrum – this can be found in Annex C.

In summary, our analysis shows that the private value of digital dividend spectrum is uncertain, but potentially considerable (GBP2.5 billion up to GBP30 billion). The high degree of uncertainty regarding the value that could be generated arises from the uncertainty of the level of interest in, and future take-up of, the underlying candidate uses. In respect of licence duration, our work suggested that for many potential uses involving significant infrastructure deployment, the majority of value will be captured over 15 years. Our assessment also concluded that the economic benefits of making spectrum available for licence-exempt services are unlikely to outweigh the opportunity cost of denying the use of the spectrum to licensed services.

We also identified *possible* market failure issues in relation to DTT (including local TV) and PMSE, suggesting that further assessment of these issues would be appropriate.

4.2 Private value (including willingness to pay for spectrum)

4.2.1 Introduction

Our underlying approach is to identify the *incremental* benefits of the use of digital dividend spectrum for each of the potential services. We undertake this by:

- developing a number of demand (macro) scenarios for the evolution of the markets associated with each of the services under consideration

- identifying the potential uses/benefits of digital dividend spectrum if it were available for each service under consideration, and what the next best alternative(s) would be if digital dividend spectrum were not available
- quantifying the incremental benefit (revenues less costs) to potential purchasers of digital dividend spectrum and therefore assessing what the willingness to pay for spectrum would be
- quantifying the incremental benefit to consumers and producers if digital dividend spectrum were available for the service under consideration.

Exhibit 4.2 below summarises our overall approach to the assessment of private value – including the assessment of willingness to pay for spectrum.

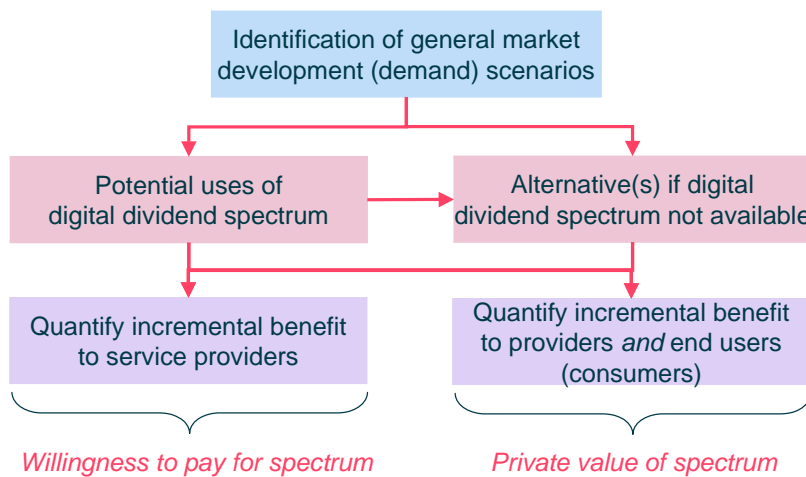


Exhibit 4.2:
Overview of approach to assessment of private value

Our general approach was to develop estimates of willingness to pay and private value, to the nearest order of magnitude, in order to inform key decisions regarding the design of the usage rights for digital dividend spectrum (e.g. licence duration), and the design of the award process (e.g. timing, potential market failure issues). Please note that we were not seeking to develop precise quantifications of the value of the spectrum to individual organisations, in the way that organisations competing for digital dividend spectrum may do so prior to participating in an auction.

4.2.2 Overview of methodology used to estimate producer surplus/willingness to pay for spectrum

Our approach involved the quantification of the net present value (NPV) of the business case (revenues less costs) for potential purchasers of the spectrum in the event that:

- digital dividend spectrum is available to provide the service
- digital dividend spectrum is not available to provide the service – where appropriate, we consider a number of alternatives to the use of such spectrum.

As shown in Exhibit 4.3, we have quantified the willingness to pay for spectrum by calculating the difference in NPV when digital dividend spectrum is available and the next best alternative if it is not available.

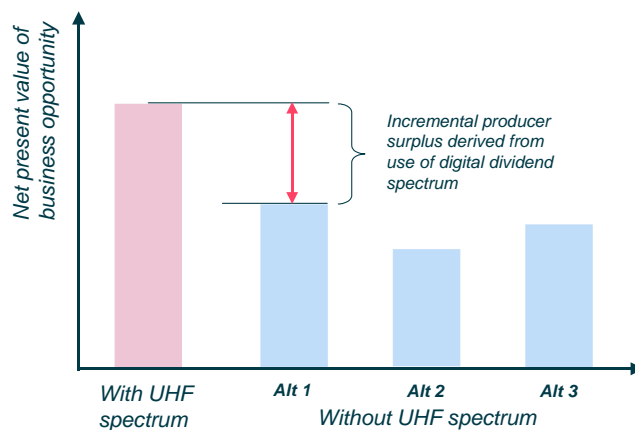


Exhibit 4.3:
Calculation of
willingness to pay
for spectrum

4.2.3 Overview of methodology used to estimate private value

We have quantified the private value of each service by considering the direct benefits to individuals from their own consumption of the service (i.e., the value consumers place on the service) less the costs of producing the service. This is equal to the sum of consumer and producer surplus, where:

- **producer surplus** is the profit earned by the producer of the service, i.e. the difference between revenues and costs (including the cost of capital)
- **consumer surplus** is the difference between consumers' valuation/willingness to pay for the service and the price actually paid.

Exhibit 4.4 summarises our approach to the assessment of incremental consumer surplus. The use of digital dividend spectrum could result in one or both of:

- an increase in the value of a service to users (e.g. through providing a better or higher quality of service) resulting in a ‘demand shift’
- a reduction in the retail price of the service to users (e.g. due to stronger price competition resulting from an increase in the number of suppliers in the market).

The combined impact of price changes and demand shift results in both a change in the number of users of the service and the value they obtain from consuming the service.

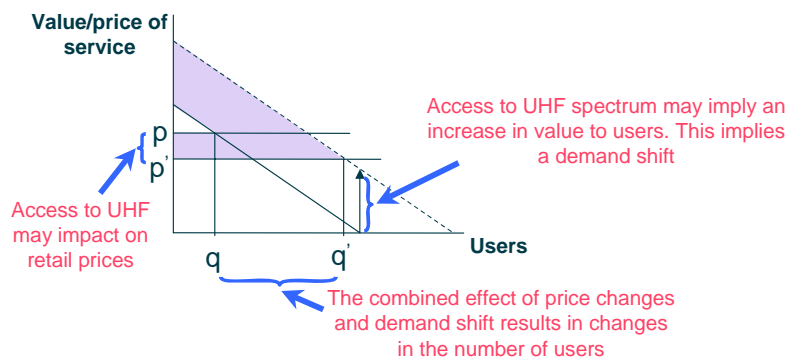


Exhibit 4.4:
Calculation of
incremental
consumer surplus

Variations in producer surplus are affected both by changes in industry costs and in market structure. The profit gains earned by the operator modelled may not always be counted as a net increase in private value, as these may be earned at the expense of other operators. In these cases, we have estimated total producer surplus both with and without access to digital dividend spectrum in order to calculate the difference. Although this calculation is not precise, it provides an indication of the likely magnitude of changes in surplus.

4.2.4 Summary of principal findings

In this section we summarise the key findings arising from our willingness to pay and private value modelling work. As indicated below, whilst overall there is considerable uncertainty over the private value that could be generated from use of digital dividend

spectrum, our modelling did highlight a number of factors which need to be considered as part of the overall design of the award process.

Potential private value generated from use of digital dividend spectrum

Our assessment demonstrated considerable uncertainty over the private value that could be generated from use of digital dividend spectrum. Overall our modelling work indicates that the total private value generated from use of the digital dividend spectrum could range anywhere between GBP2.5 billion and GBP30 billion, with the wide variation in the estimate resulting from the uncertainties associated with the potential uses of digital dividend spectrum. These uncertainties include, for example:

- how large is the additional value that individuals will place on having extra HDTV channels on the digital terrestrial platform?
- how many individuals will take up mobile multimedia services in the future, how much will they be willing to pay for the service, and will other spectrum bands (e.g. L-Band) be a reasonable substitute (e.g. from a handset availability perspective)?
- will the UHF spectrum be harmonised on a European or global basis for potential applications (e.g. mobile multimedia, cellular, broadband wireless access, licence-exempt use, etc.)?

Duration of spectrum usage rights

Our models were used to quantify willingness to pay and private value derived from the alternative uses of digital dividend spectrum from 10, 15 and 20 year periods. For those services which involved a significant deployment of infrastructure (e.g. additional DTT transmitters, mobile multimedia broadcast network, etc.), we found that the vast majority of value was captured over 15 years, and there was relatively modest additional value over 20 years. By contrast, our modelling work suggested there would be a significant loss in value if the valuation period was reduced to 10 years, although valuations generally remained positive.

Timing of spectrum availability and phasing of release of spectrum

Our modelling work considered the impact of alternative timing for making the digital dividend spectrum available under three scenarios:

- **from 2008 to 2012**, with spectrum being released on a regional basis in line with the DSO process
- **from 2010 to 2012** (e.g. if the award process were to be delayed), with spectrum being released on a regional basis as soon as DSO allowed this
- **in 2012** – i.e. after DSO is complete across the UK.

Delaying the award from 2008 to 2010 would have differing impacts, depending on the potential use of the spectrum:

- The impact on DTT (including local TV) would be small, assuming that deployment of these services were to follow the DSO time schedule¹². This is due to the fact that only a small proportion of the UK is due to be switched over before 2010 (just eight main transmitter stations covering approximately 15% of the population). Note, however, that our analysis does not take into account any extra costs that network operators may incur from a delay due to having to re-engineer additional sites that have already been designed/planned for the six base DTT multiplexes.
- The impact on the mobile multimedia market could potentially be much larger, with the exact magnitude of the delay being dependent on whether such services have been deployed in other spectrum bands (e.g. L-Band) in the meantime.
- PMSE users might benefit from such a delay if they were allowed to continue using the spectrum in the 2008–2010 period on a similar financial basis to the current licensing regime.

A delay in availability of spectrum to 2012 would potentially result in more significant losses of benefit to organisations providing services and also to consumers, with the exception of PMSE users, who might continue to benefit from use of the spectrum in the

¹² It may be possible for DTT and local TV to deploy in advance of the DSO schedule (e.g. potentially using Channel 36).

interim period. The reader should also note that potential providers of cellular and broadband wireless access services have indicated that they would not wish to deploy services on a non-national basis prior to 2012.

Potential market failure concerns

We examined the willingness to pay for spectrum and private value estimates across the range of potential services. We also considered the willingness to pay as a proportion of private value across the different services to help identify if there were any cases where the willingness to pay for spectrum may unduly under-represent the private value derived from the service i.e. where an auction may not necessarily lead to award of the spectrum to the most valuable use of the spectrum from a private value perspective (external value issues are considered in the following section). Our assessment identified the following:

- **DTT uses (HDTV/SDTV and National/Local TV):** Under certain modelling assumptions, the willingness to pay for spectrum by organisations seeking to deploy these services as a proportion of private value is lower than for other services – potentially as a consequence of the advertising model being less efficient at capturing private value than the revenue-generating models of other services. However, using alternative modelling assumptions (e.g. regarding the value of additional TV channels to individuals), the willingness to pay as a proportion of private value is more in line with other services.
- **PMSE uses:** Our assessment suggests that the willingness to pay for spectrum by this sector may be low as a proportion of total value in comparison with other potential uses of digital dividend spectrum, owing to the difficulty of realising revenues from a diverse set of users (especially community users) that reflect the true value that PMSE is generating. Furthermore, it is possible that our modelling may be understating the total value of professional PMSE use, owing to the difficulty of modelling the complex value chain into which PMSE is an input. This would in turn suggest that we may be understating willingness to pay for spectrum. While this latter point does not imply any market failure, there could be concerns that the professional PMSE community may struggle in the short term to reform their business model to the point where they can

realise a greater proportion of the value chain in the likely event that the cost of accessing UHF spectrum rises.

- **Licence-exempt services:** We have considered the benefits of making spectrum available for licence-exempt services, and compared this with the opportunity cost of denying use of the spectrum to other candidate uses. Overall we found that whilst licence-exempt services could generate significant total value, the incremental value of using digital dividend spectrum rather than alternative higher frequency bands was relatively small (and possibly even negative) in comparison with the potential opportunity cost of alternative licensed use. Annex B provides further details of our analysis.

4.3 External value

This section provides an assessment of the likely relative magnitude of incremental external value associated with the candidate services. We define external value as any additional benefits to consumers or third parties not reflected in the willingness to pay of consumers of the service. This is a broad definition of external value, which captures all types of externality, both positive and negative. For the purposes of our analysis, we divide external value into two categories:

- **Broader social value.** We use this term in relation to the value derived from services because of their broader contribution to society, for example because a service contributes to a better-informed democracy, higher educational standards or a more inclusive society. Such benefits are likely to be particularly difficult to isolate and quantify individually. This category of external value is often also referred to as ‘public’ or ‘citizen’ value.
- **Other sources of external value.** These include a variety of other externalities, such as investment spillovers (knock-on benefits for other sectors of the economy), non-internalised network effects, and health effects.

This distinction has been developed primarily for methodological reasons. In terms of their impact on the wider study, there is no difference in the way we treat these two categories.

As illustrated in Exhibit 4.5, (total) external value is simply the sum of broader social values and other external values. It is this aggregate total that matters in determining the relative risk of market failure across the candidate services.

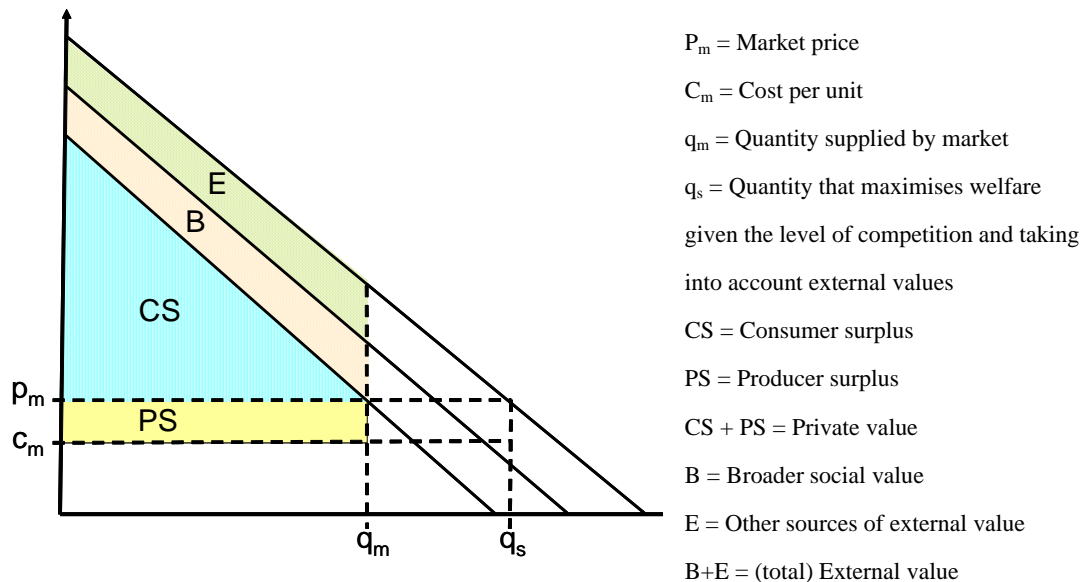


Exhibit 4.5: Measuring sources of external value

We have developed two approaches to estimating the magnitude of external values associated with various services that could potentially use digital dividend spectrum:

- Our *top-down approach*, based on bespoke market research, attempts to capture a holistic view of external value (i.e. both B and E in Exhibit 4.5) based on individual perceptions of different services.
- Our *bottom-up approach*, which is primarily qualitative, attempts to identify all significant sources of external value related to individual services, and assesses each of them separately.

As with private value, it is important to consider that many of the proposed uses of digital dividend spectrum would either be incremental to existing services or an alternative to providing the service using other spectrum or a different platform. We are therefore only concerned with the *incremental* impact on external value from use of digital dividend

spectrum for a provision of a particular service. Just as marginal private benefits tend to diminish with increased provision of a particular service, so do most external benefits. Therefore, it is quite possible that the incremental external benefits associated with providing *more* of a service are small, even though there are substantial broader social benefits associated with the service overall.

A summary of our findings in relation to both approaches is provided in the following subsections. In the case of the bottom-up approach, the analysis is split into separate sections on broader social value and other sources of external value. In the concluding part of this section, we integrate the findings.

4.3.1 Top-down assessment of external value

The top-down approach provides a holistic assessment of the external value associated with a service. It is based on the relative perceptions of private and external values associated with candidate services, as revealed through the market research conducted for Ofcom by Holden Pearmain. For practical reasons, the survey was limited to mass market consumer services: DTT (SD, HDTV and local TV), ‘mobile Internet’ (wireless broadband) and mobile TV.

The survey used a number of different approaches to estimating the aggregate external value associated with candidate services, including: ranking of candidate services based on private and total value; and referendum questions based on conjoint and chip allocation techniques. These different approaches all produced similar results:

- Overall, only modest differences were observed between private and total value (including external values) for each service, and there is no evidence to suggest that external values vary significantly across the different services.
- Analysis of the referendum-style conjoint questions indicates that, on average, respondents’ choices were not affected by the private benefits that users were perceived to enjoy. Preference shares, which indicate the preferences for different services based on total value, are very similar across services, suggesting that the value each service is seen to contribute to the country as a whole is rather similar. The only exception is mobile TV, which does not appear to be a significant factor for

respondents in determining optimal combinations of services based on their contribution to society as a whole.

- The non-conjoint ranking of services by their value to the country as a whole is very similar to the ranking by private value. This demonstrates that there are no strongly diverging preferences for services whether the assessment is on the basis of total value or on the basis of private value.
- Similarly, the chip allocation analysis shows that the relative importance of services based on private value and on total value is similar.

Although we believe the approach taken is the best possible given reasonable resource constraints, caution should be exercised in interpreting the results of this analysis; in particular, there are a number of potential concerns which should be considered. For example, it is unclear to what extent the people surveyed were capable of drawing firm distinctions between themselves (or their local communities) and a broad national good when choosing between packages of services. While there is plenty of evidence from other research that people *are* capable of drawing such distinctions, the participants may have struggled in this particular case, given some of the complexities of the situation (such as the incremental use aspect and the inclusion of new services). Although respondents were introduced to the concept of incremental use of the dividend spectrum, they may in practice have struggled to understand this. In addition, new technologies may be underestimated in this research. We note that whereas HDTV does poorly from the perspective of both private value and total value in the general sample, it does much better amongst those who have actually experienced the service.

4.3.2 Bottom-up assessment of broader social value

The measurement of the broader social value or positive externalities associated with broadcasting is quite developed. This report is more novel in that it attempts to apply such an analysis not only to broadcasting but also to the other candidate services for the digital dividend spectrum. Our analysis, alongside other external values in Section 4.3.3, draws on a broad range of primary and secondary sources. The principal primary sources are the quantitative and qualitative surveys commissioned by Ofcom from Holden Pearmain and

ORC International¹³ for the digital dividend spectrum, and the stakeholder interview reports. These were specifically tailored to focus on the issues of digital dividend spectrum and are therefore most relevant. We also conducted a systematic search of industry reports and relevant academic publications.

We break down broader social value into six categories, in terms of the contribution of candidate services to:

- **Educated citizens** (educational content, child-oriented services)
- **Informed democracy** (benefits of services, access to latest technology)
- **Cultural understanding** (reflecting and strengthening cultural identities; promoting diversity and understanding of other cultures)
- **Belonging to a community** (either ‘virtual’ in the form of connecting with other people with similar interests, or ‘local’ in the sense of participating with local community)
- **Access and inclusion** (social inclusion and universal access, ‘social glue’ provided by common references and fora, and access to public services)
- **Quality of life** (promoting quality of life through access to technologies; work-life balance; and family life).

In Annex C, we address the relative contribution of candidate services under each of these categories, both in general and based on the incremental use of digital dividend spectrum. There are some clear cross-cutting themes that emerge from the analysis, which reflect clearly perceived externalities associated with the various services:

- Broadcasting services are seen as providing benefits in terms of inclusion, belonging, cultural understanding, informed democracy and education. These are contingent upon coverage and accessibility, however, and upon the nature of the service in programming terms. The ‘captive audience’ effect whereby PSBs can deliver educational or democratic content to large audiences is arguably facing fundamental challenges. Interactive services such as BWA provide other sources of value such as access to information and expression that are not provided by TV.

¹³ ORC International undertook a deliberative research exercise in which participants were prompted with questions about the relative private and social value of candidate services, and views towards different spectrum allocation scenarios. In total, ORC organised seven group sessions in London and Bristol, each representing different social classes and age groups.

- Local TV is perceived as offering strong broader social benefits across these categories, but these will only be realised if such services attract significant viewers, which cannot be determined from the market research. Part of these benefits can be expected to be provided by broadband and satellite services.
- In a context of convergence, many of these benefits will carry across to other services that carry broadcasting, such as mobile TV (and potentially broadband access including wireless).
- Broadcasting and interactive services may also generate broader social dis-benefits. Whilst contributing to broader social value in many ways, users also perceive them as responsible for undermining social bonds and creating social isolation. This was reflected in the qualitative discussions in our deliberative research with several respondents arguing that they saw no broader social value in certain services because they in fact harm social life.
- There may be a trade-off between the broader social benefit of additional DTT channels in terms of their universal availability and the possibility that additional channels may be of low quality. In addition, some services that offer significant value, both private and public, to early adopters may have an exclusive effect that reduces the broader social value generated because they are only available to a minority.

Although substantial broader social benefits are associated with some candidate services, these do not necessarily carry over to *incremental* provision using digital dividend spectrum. In particular, although national DTT plays an important role in delivering benefits across all our categories, it is likely that most of the potential broader social benefits have already been realised through existing services, so adding more SD channels would offer little gain (and might even detract from some categories due to audience fragmentation). Similarly, our research findings indicate that wireless broadband access in general may deliver a substantial broader social value benefit across our various categories. However, because there appear to be few benefits from deploying wireless broadband using UHF spectrum rather than other, higher frequency bands where cost-effective equipment is at present more readily available, the incremental value is not as great as the general broader social value. Similar considerations may apply to cellular mobile, as there are other frequency bands that are likely to be considered to be substitutes.

By contrast, loss of broader social value is more likely to be associated with services that will be more difficult to provide without digital dividend spectrum, such as local TV or PMSE. However, even in these cases there are partial substitutes, such as wired radio microphones for PMSE, and cable and Internet delivery for local TV.

4.3.3 Other external values

The use of radio spectrum to provide particular services may also generate a variety of other external effects that do not readily fit under the heading of ‘broader social value’. These are externalities that primarily affect us as producers or consumers, rather than just as citizens. These externalities could be positive or negative. We have grouped the positive effects into three categories:

- investment spillover (including effects on UK competitiveness)
- network externalities
- non-rivalrous consumption.

We also consider potential negative effects in relation to:

- interference with other spectrum uses
- health and safety concerns
- environmental impact.

In Annex C, we address the relative contribution of candidate services under each of these categories, both in general and based on the incremental use of digital dividend spectrum. In relation to four of these categories – investment spillovers, interference, health and safety, and the environment – we found no significant sources of additional value. For two categories, we identified some issues in relation to network externalities and non-rivalrous consumption.

Network externalities

Network externalities may be generated through consumers or producers failing to take into account the benefits to others of their private consumption or production decisions.

Incremental effects associated with digital dividend spectrum will likely be small for relatively established services. However, they could be more significant for HDTV and – to a lesser extent – mobile TV, given that these services are in the earliest stages of development. If – and this is by no means certain – HDTV emerges as a dominant medium for watching TV, limits on the capacity for HD on DTT could potentially raise concerns about its attractiveness as a leading mass-market delivery platform. However, it is unclear whether the additional capacity which would be made available by using digital dividend spectrum for HD on DTT would be sufficient to solve this problem if consumer demand for HD channels is significant.

Network externality concerns have wider implications, given the current importance attached to DTT as the primary means of securing universal access, to free-to-view PSB content. As the above analysis of broader social values shows, the value attached to the contents of many PSB channels is high; therefore, if HDTV emerges as a dominant medium for PSB delivery (in much the same way as colour TV usurped black and white TV), and if PSB broadcasters are unable to reflect the realisation of this value in their bids for additional spectrum, then even if HD adds little broader social value by itself, a network externality may result. However, it is not clear that this would result in a market failure in relation to the award of the digital dividend spectrum as there are options for delivering universal access to PSB content in HD within the existing capacity of the DTT platform and, in the absence of funding considerations, not-for-profit PSBs would be likely to reflect this broader social value in their assessment of the value of additional spectrum.

Non-rivalrous consumption

This effect is relevant both to the consumption of downstream services (e.g. broadcasting services) and spectrum (PMSE). In the case of broadcasting services, the benefits from accommodating all potential users are captured in our assessment of private value for free-to-view broadcasters. However, for PMSE, there is a problem with unlicensed use of Channels 67–69 not being reflected in our private value calculations nor the willingness to pay of a band manager (even though this contributes value to society to the extent that it does not interfere with legal use). This issue is related to the problem of coordinating PMSE demand across many small users, which we explore further in Chapter 6 and Annex E on market failure.

4.3.4 Integrated assessment of external value

Our survey work has identified evidence of significant external values associated with general provision of candidate uses. However, for the purposes of this study, we are only concerned with the incremental value that is generated from using digital dividend spectrum. From the perspective of assessing market failure risks, the fact that a particular service generates high external value not reflected in willingness to pay is only relevant if the realisation of that external value is dependent on using digital dividend spectrum. If it is likely that such external benefits will be realised anyway using alternative spectrum or platforms, then the fact that a particular service generates significant broader social or other external benefits is not relevant to the design of this award.

Our top-down approach did not identify any substantial sources of *incremental* external value associated with deployment of any of our candidate services in digital dividend spectrum. On average, there is no evidence of any systematic divergence between private and total values, which might otherwise arise if incremental external values differed significantly across services. However, there are gaps in the evidence, in particular in relation to how perceptions of new services may change over time. It is also apparent that respondents can be segmented into distinct categories, with some minority groups voicing strong public preferences for particular services.

The bottom-up analysis considered a wide range of possible sources of broader social and other external values. Exhibit 4.6 below provides a summary of these findings across all our indicators. The results are broadly consistent with the top-down work. The bottom-up analysis identified a number of sources of significant external value linked to general provision of candidate services. However, in most cases – PMSE and some forms of DTT provision may be partial exceptions – the availability of alternative frequencies or other platforms for provision of the same services means that realisation of this value is not wholly dependent on access to digital dividend spectrum. Therefore, incremental values are generally modest.

	Educated citizens	Informed democracy	Cultural under-standing	Belonging to a community	Access and inclusion	Quality of life	Investment spillover	Network externalities	Non-rivalrous consumption	Interference	Health and safety	Environment
Additional DTT	– ⁽¹⁾	– ⁽¹⁾	✓	–	✓✓	✓	–	–	–	✗	–	–
Local DTT	✓	✓	✓	✓✓	✓	✓	–	–	–	✗	–	–
HD on DTT	✓ ? ⁽⁵⁾	✓ ? ⁽⁵⁾	✓✓ ? ⁽⁵⁾	–	✓ ? ⁽⁵⁾	✓ ? ⁽⁵⁾	–	✓ ? ⁽⁵⁾	–	✗	–	–
Mobile TV	✓ ⁽¹⁾	✓ ⁽¹⁾	✓	–	–	✓	–	–	–	✗	✗	✗
Wireless broadband	✓	✓	✓	✓ ⁽²⁾	✓	✓	–	–	–	✗✗	✗	✗
Cellular mobile	–	–	–	–	✓	–	–	–	–	✗✗	✗	✗
PMSE	✓	✓	✓	✓	–	✓	? ⁽³⁾	–	✓✓ ? ⁽⁴⁾	✗ ?	–	–
Home networks	–	–	–	–	–	✓ ?	–	–	–	✗ ?	–	–

NOTES: Indicative assessment only. Extent of external value is rated between zero and three ticks or crosses, where zero = negligible or no value; ✓✓✓ = significant positive external value; and XXX indicates significant negative external value; ‘?’ indicates significant uncertainty about magnitude of effect.

- 1 Value may increase if additional services are PSB.
- 2 Value will increase if ‘virtual participation and belonging’ is seen as equal in value to ‘real’ face to face participation and belonging.
- 3 Concern here is not really about investment spillovers but rather that our private value modelling may not adequately reflect consumer surplus associated with products and services that are complementary to services that use PMSE.
- 4 Primarily relates to community rather than professional PMSE use.
- 5 Presumption here is that without additional spectrum, provision of highly valued content (such as existing PSB channels) in HD may be constrained. However, note that there is some uncertainty over the extent of this effect.

Exhibit 4.6: *Estimated importance of source of external value associated with use of digital dividend spectrum for incremental provision of relevant services*

Notwithstanding the general conclusion that incremental effects are modest, it is useful to consider some of the differences between individual services:

- *More DTT channels.* The bottom-up work suggested that incremental external value associated with additional channels is low, as most broader social value is already realised through existing channels and content. Indeed, there are countervailing arguments regarding the broader social dis-benefit associated with proliferation of

channels on DTT. It is apparent from the deliberative research that most broader social value from DTT is associated with the content provided on the PSB channels, while relatively little – if any – broader social value is ascribed to some of the channels on Freeview. Regardless of the absolute magnitude of incremental external value associated with additional DTT channels, the top-down approach suggests that such external value is not substantially higher than for other services.

- *HDTV*. Provision of HDTV using DTT performs poorly from a broader social value perspective in the bottom-up assessments. It is widely seen as a luxury item. However, for most people, HDTV is not a familiar technology, and there is evidence that those who are familiar put much greater emphasis on picture quality as a component of both the private and broader social value of content. This potential linkage is significant given the high broader social value associated with PSB channels. If picture quality does become increasingly important to viewers – as ownership of large screen, HDTV-enabled TVs becomes more prevalent – then the future realisation of this broader social value may be affected by the ability of PSBs to broadcast in HD. This raises a potential concern that under-provision of HDTV on DTT might erode the wider value of DTT and potentially even undermine its future attractiveness as a leading mass-market platform. Given that deploying HDTV on DTT is very spectrum-intensive, this suggests that the availability of additional spectrum may matter. However, such an argument rests on the assumptions that HDTV will emerge as the dominant form of TV viewing that the value from HDTV cannot instead be realised using existing DTT spectrum or through alternative delivery platforms, and that DTT providers will be unable to take this into account when assessing the value of additional spectrum, none of which are certain.
- *Local TV*. Local TV scores highly across our range of bottom-up broader social value categories. However, we have concerns about how much of the perceived benefits of local TV will actually be realised, given that local TV must compete with other content such as national TV and the Internet for viewing hours, and our top-down assessment suggests that it is not the case that substantially more external value is associated with local TV than with any other service. Further, local TV provided on other platforms, such as broadband, cable and satellite, should help generate at least some of the broader social value identified in our research.

- *Mobile TV.* We found no evidence of significant external value associated with mobile TV. The bottom-up analysis indicates that it is widely perceived as a luxury, and that the associated value is predominantly private. This observation is consistent with the top-down analysis and, in particular, the referendum conjoint analysis which identified mobile TV as the only one of the five services analysed whose presence in packages was considered largely irrelevant when trading off different packages of services according to their overall contribution to UK citizens.
- *Wireless broadband.* The broader social value of wireless broadband, according to the research, derives in part from its mobility, as well as its ability to provide broadband access where fixed line services are not available. However, the digital dividend spectrum is only one of a number of candidate bands for deployment of this type of service, and is not currently the most favoured. Even if there were no wireless broadband deployed using this spectrum, it seems likely that similar provision would be provided using other spectrum. Therefore, notwithstanding findings of significant general value associated with this service, it seems likely that incremental value will be small.
- *Cellular mobile.* No significant sources of incremental external value were identified (not least because such services are already extensively provided using other frequencies which could be superior substitutes, owing to equipment availability).
- *PMSE.* UHF spectrum is the primary platform for deployment of radio microphones and talk-back systems. These services are extensively used across the UK and contribute to a range of activities with high broader social value. There would appear to be limited scope for redeployment of these services to other spectrum bands, although there may be rather more scope for them to economise on their current spectrum use across the UHF band. From a broader social value perspective, Channel 69 appears to be particularly important for PMSE, given the wide range of (often unlicensed) community users in this band. For professional users, we have a particular concern that our private value calculations may not adequately reflect the true benefits associated with their use, given the difficulty of observing the actual importance of using radio microphones and other PMSE equipment in the production of the diverse range of downstream services. However, this concern relates to the interpretation of

our modelling results and does not imply that there is external value which could result in a market failure (by not being internalised by producers).

- *Licence exempt home networks.* No significant sources of incremental external value were identified (not least because there are other (higher) frequencies available that are probably more suitable for mass deployment).

In summary, although the general finding from the research is that incremental external values associated with all candidate uses of the digital dividend spectrum are modest, there are some service-specific issues – in particular in relation to PMSE in Channel 69 and uncertainty about the significance of external value for some forms of DTT provision.

5 Award process design

5.1 Overview of award process design

In line with Ofcom's overall approach to spectrum management, whenever possible, spectrum should be awarded on a technology- and service-neutral basis via a market mechanism, i.e. an auction. In this chapter, we consider the key factors that determine the ultimate choice of packaging and auction design (Section 5.2), and set out a summary of our analysis of the available options for:

- packaging digital dividend spectrum into lots that can be offered to potential bidders in an auction (Section 5.3)
- defining usage rights attached to those spectrum lots (Section 5.4)
- designing an auction process for the allocation and assignment of digital dividend spectrum (Section 5.5)
- the timing of the award of digital dividend spectrum (Section 5.6).

The discussion in this section and the accompanying Annex D (which sets out our analysis in full) focuses purely on how a market-led process for the allocation and assignment of digital dividend spectrum could be designed. They do not address the potential implications of market failure risks, which are addressed in Chapter 6 and Annex E.

Further, for the purposes of this analysis, we make the simplifying assumption that all the released and interleaved spectrum, plus Channels 36 and 69 would be available for a market-based award. This in no way pre-judges whether it is appropriate to make all the frequencies available in this way. Our approach to packaging, usage right design and auction formats as described in this document can relatively easily be adapted to any plausible changes to the spectrum included in the award. Our main findings are presented below.

5.1.1 Packaging

There are a wide variety of packaging options for both the released and interleaved spectrum, including offering the spectrum in the form of individual 8MHz channels, aggregating adjacent channels into a small number of larger lots, and – for the interleaved spectrum – carving out regional lots.

The best approach in terms of maximising flexibility for different candidate uses and users would be to package the released spectrum into national 8MHz channels rather than aggregating channels. However, such an approach puts great emphasis on using auction design to manage bidder aggregation risks and designing usage rights that enable bidders to effectively manage the uncertainty over their prospective interference environment in a technology-neutral environment.

For the interleaved spectrum, packaging spectrum into 8MHz channels encumbered by DTT is also a plausible strategy; however, there is a good case for carving out a limited number of regional lots from the interleaved spectrum corresponding to major service regions (MSRs), so as to meet regional demand from candidate services to serve urban hotspots, such as London or Manchester.

5.1.2 Usage rights

The way in which usage rights are specified will have a big impact on the potential uncertainty for bidders regarding their prospective interference environment in a technology-neutral context. We consider the scope for different means of mitigating interference, including rights and obligations that would facilitate the co-siting of transmitters (which would seem to be an efficient way of mitigating interference problems for adjacent broadcast uses), and obligations to provide adequate frequency separation.

We conclude that it should be feasible to define effective usage rights for 8MHz national lots (plus a limited number of regional lots in the interleaved spectrum, if required), and that therefore this packaging option should be viable. However, further work is required to clarify how obligations for co-ordination (especially co-siting) and minimum frequency separations between particular pairs of adjacent technologies would function.

5.1.3 Auction design

We explore various options for the design of the award process, highlighting their relative strengths and weaknesses. We rule out single-round sealed bid options, and consider different variations of multiple-round formats, namely a standard simultaneous multiple round auction (SMRA), potentially with augmented switching rules; a package-bid SMRA; and two versions of a clock-sealed-bid hybrid. The choice of auction format is closely tied to the choice of packaging option, and whether the awards of the released and interleaved spectrum are integrated or held separately. All the proposed formats would require the development of bespoke auction rules.

5.1.4 Timing of the award

It would be appropriate to schedule an auction in 2008 (or as soon as practically possible thereafter), so as to allow winning bidders to start using digital dividend spectrum as soon it becomes available (initially on a regional basis). This approach should maximise scope for creation of economic value for UK consumers and companies.

Holding a combined auction of released spectrum (including Channel 36) and interleaved spectrum would be desirable in order to minimise substitution and aggregation risks for bidders. However, depending on the packaging approach, it may also significantly complicate the auction design. A pragmatic decision will be required on whether it is possible to combine the awards, based on a trade-off between these factors.

5.2 Key inputs into spectrum packaging and auction design

The packaging of lots and the design of the auction are determined by four key factors, as illustrated in Exhibit 5.1:

- spectrum availability and technical constraints
- the level and structure of demand
- the compatibility of candidate uses
- the policy objectives of the allocation body.

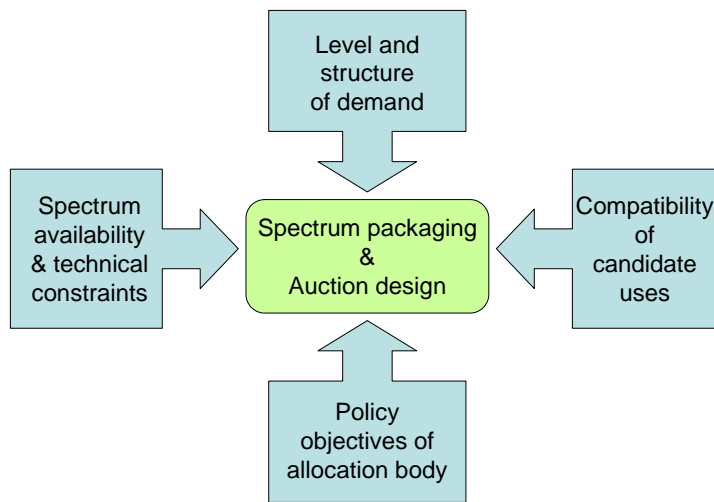


Exhibit 5.1:
*Key inputs into
 spectrum
 packaging and
 auction design*

The first three of these issues are extensively addressed in other parts of this report. Specifically, Chapters 1 and 2 address the issue of spectrum availability and the technical constraints on its use; Chapters 2 and 4 consider the level and structure of potential demand for the spectrum; and Chapter 3 addresses the compatibility of candidate uses. In addition, a detailed summary of key inputs into packaging and auction design under these headings is provided in Annex D.

In relation to policy objectives, our analysis is primarily guided by Ofcom’s primary statutory duties to ensure the optimal use of the radio spectrum in the interests of citizens and consumers. As Ofcom has set out in the SFR, it believes that this is best achieved by letting market forces play an increasingly important role in determining how spectrum is used. Ofcom believes that this will encourage efficiency in spectrum use, by increasing the likelihood that spectrum will be held by those who can make best use of it, by creating more freedom for spectrum to be used for more valuable applications, and by maximising scope for entry in downstream markets for services provided using spectrum.

This implies that spectrum usage rights and packaging should, to the greatest extent possible, facilitate use by different services and technologies, and not discriminate between them. Further, spectrum should normally be awarded using an auction. Finally, spectrum should be tradable in the secondary market, and change of use should be feasible provided that this does not cause harmful interference to neighbouring uses.

However, the reliance on market mechanisms such as auctions for the allocation and assignment of spectrum in order to achieve an efficient outcome requires certain conditions to hold. In particular, the efficiency of markets is based on the presumption that differences in the willingness to pay for spectrum closely reflect differences in the total value (i.e. private plus external value) that the respective spectrum users can generate. This means that the auction designer will have to:

- consider the potential reasons why an auction may fail to produce an efficient outcome (e.g. bidder asymmetries that might limit effective competition in the auction, information asymmetries between bidders, or differences in aggregation risks faced by bidders)
- assess the extent to which these reasons can be addressed through the choice of specific auction rules (e.g. the impact of bidder asymmetries might be reduced by limiting transparency; aggregation risks might be minimised through an appropriate auction format, appropriate spectrum packaging and rules on switching or bid withdrawal)
- identify where further regulatory interventions might be required, ranging from interventions in the auction process through bidder credits or bid subsidies, through to imposing restrictions on use or substituting an auction with an administrative allocation or assignment (note that this issue is considered separately in Chapter 6 and Annex E).

At the same time, the auction designer has to take account of the long-term impact of its choices of design parameters. The award process should not limit the scope for re-allocation and re-assignment of spectrum through secondary markets where this would be efficient in the light of changing circumstances. Further, spectrum should be packaged in such a way as to minimise any restrictions on current and future uses, and usage conditions and restrictions should be kept to the minimum required in order to ensure that spectrum can be used effectively.

Where it is not possible to package spectrum in a neutral way (e.g. because different potential users have different requirements in terms of channel width, contiguity or pairing of frequencies), and where certain limitations are required (in order to manage incoming and outgoing interference), it is important to identify those potential spectrum uses that are likely to generate the highest value to society, and choose design parameters that are most favourable to those uses.

5.3 Spectrum packaging

The packaging of spectrum plays a key role in determining what services and technologies are likely to be deployed in the available spectrum. A core objective for this award is to maximise the flexibility for deploying different technologies in the digital dividend spectrum, either directly through the award or through subsequent changes in use. However, this objective has to be balanced against the need to ensure an efficient allocation and assignment of frequencies, which in turn depends on providing bidders in an auction with reasonable certainty about the potential auction outcomes that they may experience – both in terms of spectrum endowment and the interference environment. In Annex D, we develop a number of options for packaging both the released and interleaved spectrum. A summary of these options is provided here.

5.3.1 Packaging options for the released spectrum

Key inputs into packaging choices for released spectrum

The following issues stand out as having particular relevance to the development of packaging options for the released spectrum and for Channels 36 and 69 (if included in the same award):

- *International constraints.* The UHF band is currently planned across Europe for TV use on the basis of specific 8MHz channels, and use of each channel in the UK is subject to a distinct set of interference constraints. The nature of these constraints implies a strong case for having packages which are built around the existing 8MHz channels.
- *National versus regional demand.* A substantial majority of demand is for national channels. This includes DTT multiplex operators who, although they only use spectrum on a regional basis, could probably best achieve this by buying national capacity and on-selling geographic usage rights that they do not need. Where there is regional demand for prospective uses, this might be accommodated most effectively using (retained or newly created) interleaved spectrum, or by buying access to capacity or frequencies on a regional basis in the secondary market.

- *Spectrum endowment required.* Requirements for spectrum endowment vary widely, from as little as 8MHz for some mobile TV deployment options, up to twelve 8MHz channels for one of the options for a high-coverage DTT multiplex, with many levels of potential intermediate demand. It appears that the only ‘base unit’ of demand that could satisfy all potential uses is 8MHz channels based on the current band plan, which implies that the spectrum should either be packaged as individual channels or in larger blocks formed from multiple contiguous channels.
- *Contiguity.* The candidate uses differ significantly in their preferences for contiguous spectrum. In the case of wireless broadband and cellular mobile, contiguous assignment is probably essential to assemble a usable block of spectrum. Such bidders may benefit from having larger packages (i.e. multiple adjacent 8MHz channels) as this would make it easier to assemble a usable block of spectrum. By contrast, for DTT, having contiguous assignment is a secondary concern compared with assembling a set of specific channels that can maximise population coverage, taking into account international obligations. The same may also be true, albeit to a much lesser extent, for a mobile TV operator deploying a multi-frequency network strategy. These bidders may strongly value the flexibility to build their own packages by targeting combinations of specific 8MHz channels spread throughout the released spectrum.
- *Compatibility.* It will not be feasible to deploy many of the possible pairs of candidate uses in adjacent spectrum without mitigation efforts such as co-siting or frequency separation. Given that bidders in a technology-neutral auction are necessarily uncertain as to what type of use may occupy adjacent spectrum, it will be very important to define usage rights in a way that reduces the level of uncertainty about the potential interference environment and/or potential mitigation obligation that bidders may face, and that helps successful bidders to come to an agreement how to co-ordinate their use in the most cost-effective manner. Uncertainty can be reduced by constraining usage rights at boundaries, but this may also reduce the amount of usable spectrum available. In this context, having larger packages in order to reduce the number of (potential) boundaries may be an advantage.
- *Specific requirements.* Certain candidate uses have specific preferences for particular frequencies. This has implications for packaging, in that ideally the design of packages should avoid closing off or restricting these preferences. Notably, spectrum demand for

mobile TV is focused on Channels 31–40, with little or no interest in Channels 63–69. Given that mobile TV users require relatively small packages (just 1–3 lots), packages in the lower range should ideally not be so large as to discourage such users from bidding.

Where these preferences conflict, it is necessary to consider the relative merits of packaging and auction design in order to deal with any potential trade-off.

Analysis of packaging options for released spectrum

Taking these considerations into account, we have identified three candidate options for packaging the released spectrum, also illustrated in Exhibit 5.2 below:

- **Option R1: Individual channels.** 16 lots of 8MHz, corresponding to Channels 31, 32, 33, 34, 35, 36, 37, 39, 40, 63, 64, 65, 66, 67, 68 and 69.
- **Option R2: Medium-sized blocks.** Eight lots of varying sizes, corresponding to Channels 31–33 (24MHz), 34–35 (16MHz), 36–37 (16MHz), 39–40 (16MHz), 63–64 (16MHz), 65–66 (16MHz), 67–68 (16MHz) and 69 (8MHz).
- **Option R3: Large blocks.** Five lots of varying sizes, corresponding to Channels 31–34 (32MHz), 35–37 (24MHz), 39–40 (16MHz), 63–68 (48MHz) and 69 (8MHz).

	21-30	31	32	33	34	35	36	37	38	39	40	41-62	63	64	65	66	76	68	69
OPTION R1 (14 lots)		31	32	33	34	35	36	37		38	39		40	41	42	43	44	45	46
OPTION R2 (8 lots)		A			B		C			D			E		F		G		H
OPTION R3 (5 lots)		A				B				C			D						E

Exhibit 5.2: *Illustration of packaging options for the released spectrum*

Note that all three options include Channel 69 as a standalone lot of 8MHz. This reflects the fact that there would likely be uniquely strong demand from a PMSE band manager for this specific channel, owing to the high level of existing PMSE use in that channel. Aggregating this channel with other channels would therefore unduly discriminate against

PMSE bidders. Note also that if Ofcom decided to exclude Channel 69 from the award, this would not affect the packaging of any other channels under our proposed options.

A detailed comparison of our three options is provided in Annex D. In summary, we find that:

- **Option R1 (8MHz channels as lots)** maximises flexibility for bidders. It keeps alive all plausible auction outcomes, encourages competition for all available lots across all bidders, and maximises the likelihood of multiple entry in any particular service category. However, this flexibility may also be a source of uncertainty for bidders regarding the future interference environment, in that it may be difficult for them to identify the likely number or location of boundaries between technologies. The impact of this uncertainty on different candidate uses strongly depends on the definition of usage rights. The flexibility may also require a relatively complex auction design in order to address and mitigate the aggregation and exposure risks faced by bidders requiring multiple 8MHz channels.
- **Option R3 (larger packages of contiguous channels)** is less flexible. It precludes a wide range of plausible auction outcomes which could, in practice, be the most efficient. They may be particularly disadvantageous to bidders who may want just one or two 8MHz lots (e.g. mobile TV) or that may want to cherry-pick specific lots across the released spectrum (e.g. a high-coverage DTT multiplex provider). The limited number of lots may also reduce the scope for multiple entry in some service categories, especially mobile TV. On the other hand, having different sized lots may encourage bidders with particular uses in mind to target specific lots. For example, mobile TV bidders could be expected to target lots B or C (in Exhibit 5.2 above), whereas a wireless broadband bidder would probably prefer lots A or D. This does have the advantage that it is not only easier for bidders to predict the number and location of boundaries between users, but also to predict where particular services might locate, which would reduce uncertainty over interference.
- **Option R2** is a compromise between the two other options which exhibits both the strengths and weaknesses associated with the two other options.

It is apparent from this analysis that there is no leading option for packaging that would in itself be most likely to generate efficiency in allocation and assignment of spectrum.

Option R1 maximises flexibility for bidders, which should normally be consistent with promoting an efficient assignment, but could be compromised if bidders' willingness to pay is undermined by uncertainty over their interference environment. By contrast, Option R3 could reduce uncertainty over interference for bidders, which may support more aggressive bidding, but risks closing off potentially efficient outcomes. If it is possible to define appropriate usage rights and to devise an auction format that allows bidders to manage their aggregation and exposure risks, then Option R1 appears to be the front runner. Otherwise, Option R3 may be preferable.

5.3.2 Packaging options for the interleaved spectrum

Key inputs into packaging options for interleaved spectrum

The supply characteristics and structure of demand for the interleaved spectrum are distinct from the released spectrum. The key differences are that access to interleaved channels will necessarily be on a geographic basis, and that there is viable demand for spectrum in smaller service areas, which released spectrum can largely be discounted.

Much of the analysis above in relation to the released spectrum carries over to the interleaved spectrum. In particular, there is a strong case, on co-ordination grounds, for following the existing band plan with 8MHz channels. As with the released spectrum, use of interleaved spectrum is subject to international co-ordination and must be co-ordinated with domestic DTT use. In addition, there seems little, if any, benefit from disaggregating 8MHz channels by frequency, given the lack of demand for licences with smaller spectrum endowments.

There are, however, some significant differences in the structure of supply and demand:

- In each channel, unencumbered spectrum is only available on a regional basis. The pattern of regional availability varies from channel to channel, so there is relatively little scope for assembling geographically contiguous blocks of spectrum of more than 8MHz. This is a significant difference from the released spectrum, where one of the possible motives for having larger blocks is to meet the needs of bidders requiring contiguous spectrum.

- Potential uncertainty over the prospective interference environment due to uncertainty over the number and location of boundaries between different technologies is still relevant. However, the fact that use of interleaved spectrum is already constrained by the need to co-ordinate with incumbent DTT use may tend to limit the relevance of this issue, as the usage restrictions required in order to protect incumbent DTT use may effectively prevent use of the spectrum for wireless broadband and cellular, and limit the way that other services – such as mobile TV – can be deployed.
- Matching the regional availability of interleaved spectrum, there may be significant demand for spectrum on a regional/local area basis. While this demand also applies to released spectrum, it is much more likely to be a viable use for interleaved spectrum.
- Demand for spectrum on a regional basis is particularly focused on the major urban areas. Interleaved spectrum that offers capacity in such regions will likely be the focus of bidding from local TV and PMSE, and possibly also other potential uses such as national DTT and mobile TV which would ideally prefer released spectrum.

Finally, we note that there may be policy or market failure reasons for Ofcom to intervene in the packaging of interleaved spectrum to support particular candidate services (e.g. PMSE or local TV). This issue is discussed in Chapter 6 and Annex E on market failure. For the purpose of assessing packaging options, Ofcom has asked us to proceed on the working assumption that no such intervention is necessary.

Analysis of packaging options for interleaved spectrum

Taking these considerations into account, we have identified four candidate options for packaging the interleaved spectrum, also illustrated in Exhibit 5.3:

- **Option II: Nationwide channels.** 32 lots of 8MHz, based on existing interleaved channels, each encumbered by DTT use. Awardees could potentially be given the right to exploit the entire channel, subject to not causing harmful interference to incumbent DTT provision.

- **Option I2: Nationwide channels and MSRs.** Under this option, additional lots based on MSRs would be carved out from the available interleaved channels. Further work would be required on what constitutes an MSR, but we would expect that MSRs would be limited in number and correspond to one or more adjacent DTT transmitter areas associated with high urban populations (e.g. London, Manchester, etc.), where demand for interleaved spectrum is expected to be particularly strong. Each channel in each MSR would be sold separately. The remaining spectrum in the interleaved channels could either be sold as 32 encumbered nationwide channels (as in Option I1), or potentially grouped together into larger blocks of contiguous channels (as in Option I4).
- **Option I3: Local service areas.** Each channel is divided into distinct service areas, which are either encumbered or not encumbered by DTT use. These could, for example, be based on the 120 high-power DTT transmission stations that formed the UK input into the RRC process, which would imply having 3840 lots (32×120) of interleaved spectrum. Only lots which are not substantially encumbered by DTT would be awarded in the auction. Further work would be required to determine whether it would be possible to define the same set of local service areas across all channels, or whether variations in the way DTT multiplexes are deployed may require variation in the geographic boundaries of service areas across channels.
- **Option I4: Large national blocks.** The available spectrum is carved up into three roughly equal blocks of 80MHz (channels 21–30), 80MHz (41–50) and 96MHz (51–62). Awardees could potentially be given the right to exploit channels across their entire blocks, subject to not causing harmful interference to incumbent DTT provision.

Option	Type of lot	Channels																																																													
		21	22	23	24	25	26	27	28	29	30	31-40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63-69																												
I 1	National	[Red/Blue blocks for channels 21-30]																														[Red/Blue blocks for channels 41-62]																															
		[Red/Blue blocks for channels 21-30]																														[Red/Blue blocks for channels 41-62]																															
I 2 (variant with 32 national lots)	National	[Red/Blue blocks for channels 21-30]																														[Red/Blue blocks for channels 41-62]																															
	MSR	[MSR A/B blocks for channels 21-30]																														[MSR A/B blocks for channels 41-62]																															
	MSR	[MSR A/B blocks for channels 21-30]																														[MSR A/B blocks for channels 41-62]																															
	MSR	Continued for each Major service area (MSR)																																																													
I 2 (variant with 3 national lots)	National	[Red/Blue blocks for channels 21-30]																														[Red/Blue blocks for channels 41-62]																															
	MSR	[MSR A/B blocks for channels 21-30]																														[MSR A/B blocks for channels 41-62]																															
	MSR	[MSR A/B blocks for channels 21-30]																														[MSR A/B blocks for channels 41-62]																															
	MSR	Continued for each Major service area (MSR)																																																													
I 3	LSR	[LSR A/B/C blocks for channels 21-30]																														[LSR A/B/C blocks for channels 41-62]																															
	LSR	[LSR A/B/C blocks for channels 21-30]																														[LSR A/B/C blocks for channels 41-62]																															
	LSR	[LSR A/B/C blocks for channels 21-30]																														[LSR A/B/C blocks for channels 41-62]																															
	LSR	Repeated for each local service area (LSR)																																																													
I 4	National	[Red/Blue blocks for channels 21-30]																														[Red/Blue blocks for channels 41-62]																															

KEY: or Available lot Unavailable spectrum

NOTES:

- Under Options I1, I3 and I4, all the available national lots are encumbered by DTT use in specified geographic areas.
- Under Options I2 and I3, examples of lots available for major service regions (MSR) or local service regions (LSR) are purely illustrative and do not correspond to availability in actual regions of the UK. Under Option I3, only service areas not encumbered by DTT would actually be available in an auction.
- Note also that for Options I2 and I3, this illustration assumes that it is practical to use the same service areas across all lots (see main text for discussion of this issue).

Exhibit 5.3: Illustration of packaging options for the interleaved spectrum

A detailed comparison of the options is provided in Annex D. In summary, we find that:

- **Option I1** provides great scope for bidders to assemble packages of channels across the available spectrum that match their specific demand. This may be particularly attractive for potential mobile TV and DTT bidders seeking near-national footprints, provided that the auction design can address their aggregation risks. This approach should also be attractive to a PMSE band manager. However, it is less suited to bidders with regional demand, such as local TV, who must either buy more spectrum than they need or rely on the secondary market. This option is similar to our Option R1 for packaging the released spectrum, as both envisage national 8MHz channels. It should be feasible to integrate them into one process with 46 (or more) lots of 8MHz.
- **Option I2** is an augmentation of either Option I1 or I4, offering bidders some limited scope to express demand for major regions. By accommodating a greater range of potential demands, it can support a wider range of (potentially) efficient outcomes, while avoiding the significant increase in complexity associated with the fully regional approach envisaged under Option I3. This may also reduce dependence on the secondary market to resolve inefficiencies in assignment at the end of the primary award. This approach would be more challenging to integrate into a single award with the released spectrum than Option I1, but integration would be feasible.
- **Option I3** maximises flexibility for bidders. It allows both regional and national bidders to compete for the specific spectrum assignments that match their requirements, thus keeping alive all plausible auction outcomes. However, the large number of lots potentially creates great complexity, both for Ofcom (which must design a suitable auction and define individual usage rights) and for bidders (who must grapple with the strategic complexity of aggregation and substitution choices across these lots). Such complexity may be hard to justify in this case, given that many bidders would probably be satisfied with national lots, and regional demand is likely to be focused on a few areas. Having so many lots would also make it more difficult to integrate this award with the released spectrum.
- **Option I4** represents a significant simplification relative to other packaging approaches. With just three lots, the award process would be straightforward, and could easily be integrated with an award of the released spectrum. However, this

simplicity comes at a potentially high price. The proposed large packages are not a good fit with the demands of any of the potential bidders, except perhaps for a PMSE band manager. Many feasible and potentially efficient allocation outcomes would be ruled out, creating a heavy burden on the secondary market to resolve inefficiency.

All four approaches have strengths and weaknesses. We have particular concerns as to whether the complexity of the regional process under Option I3 can be justified, given the nature of existing demand. Meanwhile, Options I1 and I4, the two approaches with only national lots, might place a significant burden on the secondary market to meet any regional demand that could not be served in the auction. If there is concern that the secondary market cannot be relied on fully to address any inefficiencies in the primary assignment, then Option I2 – linking together national lots with some regional lots (MSRs) – may offer an effective compromise.

It is also worth noting that under Option I2, the extent to which MSRs are carved out will have a big impact on the value and attractiveness of the remaining spectrum in the national channels. If the national channels are denuded of urban areas to the extent that they are primarily attractive only to PMSE bidders that need spectrum for occasional use, then the efficiency concerns we have expressed above about amalgamating contiguous blocks of channels into packages would be muted.

5.4 Specification of usage rights

Spectrum usage rights describe the set of conditions under which a frequency licence can be used. They typically describe:

- the spectrum endowment and geographic area in which the licence is valid
- the rights and obligations of the user (which determine the interference environment in which it and its neighbours may operate)
- the duration of the licence.

In the following subsections, we provide a summary of options for designing usage rights for both the released and interleaved spectrum, and discuss the duration of usage rights. A more extensive analysis is provided in Annex D.

We conclude that it should be feasible to define effective usage rights for 8MHz national lots in the released and interleaved spectrum (plus a limited number of regional lots in the interleaved spectrum, if required), and that therefore the related packaging options should be viable. However, further work is required to clarify how obligations for co-ordination (especially co-siting) and minimum frequency separations between particular pairs of adjacent technologies would be defined.

5.4.1 Rights and obligations for usage rights in the released spectrum

Proposed usage rights for 8MHz national channels

<i>Obligations</i>	<i>Rights</i>
All users would be subject to the following obligations:	All users would have the following rights:
<ol style="list-style-type: none"> 1. Outgoing interference must not exceed specified levels at test points in neighbouring countries, based on RRC agreements for DTT (i.e. interference must be below the level that would have been generated if the DTT transmit mask had been used at specified transmitting sites in the UK). 2. Base station deployment must be co-ordinated with other users in neighbouring (adjacent or geographic) channels – at a minimum this would require timely provision of specified data to a database. 3. Interfering parties must allow victims in other UHF channels to co-site at their base station on reasonable terms. 4. Unless otherwise agreed between neighbouring users, users deploying roaming terminals with a return path must deploy a frequency separation between high power transmissions and adjacent channel use. This 'guard band' can only be used for defined low-power transmissions. 	<ol style="list-style-type: none"> 1. Users may deploy any service or technology, subject to observing their obligations. 2. Where users own adjacent lots, co-ordination and frequency separation obligations would only apply at the external boundaries of their spectrum holdings. 3. Users may propose revisions to their obligations based on negotiations with neighbouring users, but these must be approved by Ofcom (which may require evidence that changes will not cause harmful interference to third parties nor breach UK international obligations). 4. Users have the right to co-site their equipment at the base stations of neighbouring users on reasonable terms if they can demonstrate they would otherwise suffer harmful interference.

Exhibit 5.4: *Broad specification of usage rights for 8MHz channels on a service and technology neutral basis*

Exhibit 5.4 above provides a broad specification of the usage rights that could be applied to spectrum packaged into 8MHz national channels, as described in packaging Option R1 for the released spectrum.

In principle, the approach summarised here would appear to offer a viable and relatively straightforward way to define the usage rights. Using the RRC limits avoids the need for Ofcom to define separate power level or spectrum masks, and ensures that all potential uses will conform to the UK's international obligations. Although users are not directly protected from hole-punching, this approach gives broadcast users a choice between buying more spectrum and using frequency separation to manage interference, or buying less spectrum and, if necessary, taking advantage of the co-siting option. Users deploying roaming terminals that transmit back to base stations (WiMAX, UMTS TDD, UMTS FDD) are under more wide-ranging obligations because the co-siting option for avoiding interference would not be feasible in their case. They would need to protect neighbouring users through provision of a frequency separation.

Further technical work will be required to define many of the rights and obligations described in Exhibit 5.4:

- *Interference.* It may be necessary to define what is meant by 'interfering party' and 'victim' in clause 3 (under Obligations), so as to establish a minimum threshold for co-siting obligations to apply.
- *Co-ordination.* Defining a general obligation to co-ordinate is not straightforward, although Ofcom does have experience of this in relation to other actual or proposed awards. This is a potential source of uncertainty if bidders are unsure how their neighbours will interpret this obligation. There may also be some requirement for Ofcom to offer a dispute resolution service.
- *Frequency separation.* The size of the frequency separation in clause 4 will need to be defined, as will the low-power restrictions on use of frequency separations. Both could be estimated using Monte Carlo modelling for different pairs of technologies, based on specified definitions of acceptable interference.

A decision is also required on the extent to which incumbent uses in the digital dividend spectrum should receive protection from new uses of the released spectrum.

Usage rights under alternative packaging options

Having larger packages consisting of multiple, contiguous 8MHz channels may make defining user rights somewhat easier, as:

- the number of potential boundaries between users for which co-ordination or separation restrictions apply is reduced
- it may be possible to rely more generally on a requirement on users to provide frequency separations without creating uncertainty for bidders that may be left with too little usable spectrum to deploy their service, thus reducing uncertainty about the likely cost that a bidder might have to incur for co-siting to avoid hole-punching
- the burden of providing frequency separations can be split more evenly between adjacent packages or, alternatively, applied disproportionately on larger packages, without falling disproportionately on certain types of user.

Put differently, a reduction in the number of boundaries and a greater emphasis on frequency separation rather than co-ordination (which is harder to define) may facilitate greater certainty for bidders in an auction.

In practice, however, these benefits may be somewhat illusory, as:

- Many of the rights and obligations are determined by the need to protect incumbent uses, at home and abroad, and may in some cases apply to channels irrespective of whether they are lots in their own right or components of larger packages.
- If, under the individual 8MHz channel approach, bidders are uncertain about their ability to manage co-ordination on a cost effective basis, they always have the option to bid for multiple, contiguous lots, and mitigate interference using frequency separation. Auction design can facilitate such an option by allowing package bids. By contrast, the larger package option is a blunt tool, as it closes off the individual channel co-ordination option.
- The absence of usage rights for individual channels may impede disaggregation of larger packages in the secondary market, as users do not have a clear starting point from which to negotiate terms.

- In the absence of technical information on adjacent holders of spectrum, the expectation as to the amount of spectrum that would be required in order to ensure separation may not be subject to any greater certainty than would attach to a co-ordination process.

In summary, the extent to which the technical issues outlined above can be resolved may have important implications for the choice of packaging. If the technical concerns can be resolved, this may largely eliminate one of the benefits from having larger blocks of spectrum in the auction, as opposed to lots based on individual 8MHz channels.

5.4.2 Rights and obligations for usage rights in the interleaved spectrum

Proposed approach for national 8MHz channels

If the interleaved spectrum is also packaged into individual 8MHz channels, as envisaged under Option I1, then it should be possible to apply broadly the same usage rights as described for the released spectrum in Exhibit 5.4 above. However, interleaved usage rights would need to be restricted, additionally, by maximum field strengths at test points in and around existing DTT service areas to ensure compatibility. Such an approach would simply mimic standard multi-frequency network planning.

Further, it will also be necessary to define exactly the property rights of DTT incumbents, based on their current transmitter networks and any planned expansion. Clearly, it would not be feasible to auction these lots if there was uncertainty about further expansion of transmitter sites by DTT incumbents, as this may affect how much usable spectrum there is for a new user to exploit.

One way to manage the relationship between the DTT incumbent and users of interleaved spectrum, may be to sell *management rights* to the whole channel, encumbered by DTT use. The management rights holder would have the right to exploit the channel to provide its own service, or lease access to third parties, subject to protecting the DTT user from undue interference. Maintaining a single management right may facilitate co-ordination with the DTT user, for example over deployment of repeater stations and co-siting. This may be preferable to allowing geographic disaggregation of usage rights without a

management right, in which case the DTT user may find that it has to negotiate with many parties.

In all cases, great attention will need to be paid to defining the acceptable statistical risk of interference to existing services. If even a few households lose their DTT coverage as the result of a new entrant, this may be politically unacceptable.

Usage rights under alternative packaging options

Amongst the other packaging options considered for the interleaved spectrum, Option I3 would seem to create a significant regulatory burden, as a usage right would need to be defined for each lot – and there would be potentially hundreds of lots. Further, setting conditions at the geographic boundaries of these local areas is a non-trivial technical exercise, given uncertainty over which technologies may be deployed in adjacent areas. These issues also apply to Option I2, but clearly the regulatory burden is much less, as the number of regional lots is limited to a few MSRs.

Under Option I4, having larger packages of national lots in the interleaved spectrum does not obviously greatly reduce the burden of defining usage rights relative to having individual national channels as lots. This is because each interleaved channel will anyway have a distinct set of rights defined owing to the constraints imposed by incumbent DTT use. The constraints on other uses of the interleaved spectrum owing to the need to protect DTT incumbents also imply that there is less scope for uncertainty over the range of technologies that can be deployed in adjacent channels, which in turn implies that uncertainty over the interference environment should typically be less of an issue for bidders than for the released spectrum.

5.4.3 Duration of usage rights

Ofcom's standard approach to licence duration for new awards is to issue indefinite usage rights. These are guaranteed for a minimum term, during which the licences can only be revoked under exceptional circumstances such as a national emergency. Beyond this minimum term, licences can also be revoked for spectrum management reasons, subject to

a reasonable notice period. We see no reason to deviate from this standard approach for licences in the digital dividend spectrum, whether for released or interleaved spectrum.

The length of the initial minimum term needs to be sufficient to allow companies certainty with respect to realising an adequate return on their investment. Based on our modelling of the business cases for deploying various technologies in this band, we believe that a minimum term of at least fifteen years would be appropriate for this spectrum.

5.5 Auction design

This section addresses the design of an auction to award the digital dividend spectrum. We begin by summarising the key choices in auction design, which we then use to identify three broad categories of auction format, all of which involve bidding simultaneously for lots over multiple rounds. Overall, we observe that there is no single format that is best under all circumstances. Indeed, the optimal format may vary depending on the choice of packaging option and whether the awards of released spectrum and interleaved spectrum are held separately or integrated. A more detailed description of the auction formats and a comparison of their strengths and weaknesses is provided in Annex D.

5.5.1 Key choices in auction design

In selecting the appropriate format for the auction, there are a number of key choices that will need to be made, in particular:

- whether to have separate or combined awards for the released and interleaved spectrum
- whether to use an ascending bid (multiple round) format or a sealed bid (single round) format; or a hybrid of the two approaches
- whether to use pre-determined or generic lots¹⁴
- whether to allow package (combinatorial) bidding

¹⁴ With pre-defined lots, bidders place bids for lots at specific frequencies. By contrast, with generic lots, bidders simply specify the number of lots that they want within a particular category at a given price. The actual frequencies that they are awarded are sorted out in a follow-up process.

- how transparent to make the auction process (i.e. what information about bids and bidders to reveal before, during and after the award).

These choices are discussed in detail in Annex D. In summary, we find that:

- There is a strong case for integrating the award of interleaved spectrum into an auction of released spectrum, provided that this can be done without creating undue complexity and uncertainty for bidders wanting the more valuable released spectrum. Owing to demand linkages between the two categories of spectrum, many bidders would face aggregation and/or substitution risks if they are not sold in the same award under appropriate auction rules. However, it is also evident that interleaved spectrum is an inferior substitute for released spectrum. Consequently, it would not be appropriate to link the bands if there is a significant risk to the efficiency of the process for released spectrum, which is the award of most importance to UK society. In practice, the scope for linking the awards may depend on the packaging approach and complexity resulting from the number and nature of available lots.
- There is a strong case for using a multiple round format, which may or may not be augmented by a final round sealed bid. A multiple round process is appropriate, as many bidders are likely to face a high level of common value uncertainty, and therefore would benefit from observing the behaviour of others over successive rounds. We have also not identified any sufficiently strong bidder asymmetry or competition concerns to justify using solely a single round, sealed bid. There is, however, a good case for using a hybrid process with a multi-round process following by a sealed bid final round, if this can facilitate the use of package bidding.
- An approach using pre-determined lots would be possible for all packaging options. There may be scope to use generic lots to simplify the auction process for some of the packaging options with larger numbers of lots. In particular, there may be some scope to use generic lots for the interleaved spectrum if a regional approach is adopted.
- Package bidding is desirable to address aggregation risks, subject to not causing undue auction complexity for bidders. Without package bidding, some of the more disaggregated packaging options may create undesirable risks for those potential users that have minimum requirements for large numbers of lots (notably, DTT, cellular

mobile and wireless broadband). However, given the potentially large number of lots involved, it may be necessary to place constraints on the way that package bids are expressed, for example by using a clock auction-sealed bid hybrid approach.

- A highly transparent auction format is likely to be desirable (unless concerns about low competition emerge), as this will help bidders manage common value uncertainty.

5.5.2 Candidate auction formats

Building on these findings, we have developed four candidate auction formats which could plausibly be used for this award:

- a standard simultaneous multiple round auction with pre-defined lots, which could be augmented by either limited withdrawals or augmented switching
- an SMRA with pre-defined lots and package bidding
- a clock-sealed-bid hybrid with each lot as a unique category (equivalent to having pre-defined lots)
- a clock-sealed-bid hybrid with a more limited number of categories of generic lots.

A brief description of these formats is provided below. A more detailed descriptions and comparison of their strengths and weaknesses is provided in Annex D.

Standard SMRA

The standard SMRA format was pioneered in the 1990s by the FCC in the USA to sell large numbers of lots simultaneously. Bidders make multiple, independent bids for pre-defined lots, and manage aggregation and substitution risks either by switching their demand between lots when they are overbid, or by withdrawing high bids, subject to possible penalties. This is a tried and tested format that would be relatively simple to implement. Unfortunately, the standard SMRA has a number of well-known drawbacks:

- Bidders are exposed to the risk of ‘stranded licences’, i.e. either winning spectrum on a non-contiguous basis or winning only a subset of the lots they actually want.
- With many lots, the format may be strategically complex for bidders and is potentially vulnerable to strategic behaviour which could distort the auction outcome.
- The format may be slow to implement. Standard SMRAs are especially slow near the end, when there is little excess demand.

The weakness of the format in addressing the exposure problem and its potential vulnerability to strategic behaviour raise particular concerns in relation to this award. Under most of our packaging options, many of the candidate bidders – in particular for the released spectrum – may have irreducible demands for numbers and combinations of lots. This leaves them potentially significantly exposed to aggregation risks under any auction approach that does not allow for package bids that are accepted or rejected in their entirety.

The issue of strategic behaviour affects, in particular, the interleaved spectrum. There may be a large number of lots, many of which are very different and will have predictable (albeit uncertain) differences in demand and value. These differences create potential opportunity for strategic behaviour, such as parking and punishment strategies. By using activity rules with different eligibility for different types of lots, we may be able to reduce gaming incentives, but it will probably not be possible to eliminate them.

In summary, the basic version of the SMRA is not a good candidate for this award, as there is a severe risk of an inefficient outcome due to bidder aggregation risks and strategic bidding. It is possible to adapt the format – for example using augmented switching¹⁵ and other detailed activity rules – to increase the likelihood of an efficient outcome. Such an approach may be an acceptable fall back option, especially for the interleaved spectrum, if this were divided into many lots and auctioned separately. However, it is clearly a second-best approach if a workable package bid format can be developed.

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A variant of the standard SMRA used in the 2004 Norwegian FWA auction. See Annex C for more details.

SMRA with package bidding

This is another variant of the standard SMRA. In this case, package bidding is introduced, i.e. bids are allowed for combinations of lots as well as for individual lots. In each round, bidders can submit mutually exclusive bids for every combination of lots that they would be content to win at the current prices. With large numbers of lots, package bidding can quickly become very complex. However, complexity can be reduced by constraining the types and/or numbers of combinations that bidders can bid on in each round of the auction.

The package auction progresses in a similar way to the standard SMRA. The auction continues for as long as there is excess demand, with prices increased in increments in each round. At the end of each round, a set of highest bids are identified, and these remain as highest bids unless displaced by a new set of bids with a higher aggregate value.

In principle, a SMRA with pure package bidding and pre-determined lots is a very attractive solution for this award, given the substantial aggregation risks faced by many bidders, especially for the released spectrum. In practice, however, for any solution that involves a large number of lots, the resulting complexity for both the auction design and for bidders would be a significant barrier to running an effective auction process.

Therefore, the SMRA with package bidding and pre-determined lots is most obviously a candidate in the case that the released spectrum is awarded alone. With up to 16 lots and a limited number of acceptable packages, it should be feasible to manage the complexity of this process. If the award is extended to include the interleaved spectrum, then the resulting complexity in terms of the number of lots and combinations may be so large as to offset the efficiency benefits presented by package bidding in terms of managing aggregation risks.

Clock-sealed-bid hybrid

The clock-sealed-bid hybrid is a two-stage auction format, consisting of a clock auction, followed by a sealed bid. This approach allows (limited) package bidding without introducing the complexity of a pure package bid SMRA. The objective is to eliminate aggregation risks without introducing undesirable complexity for bidders.

Clock auctions are a simple form of SMRA used for selling multiple generic lots. In a clock auction, the price per lot is increased steadily over consecutive rounds, with bidders in each round indicating their demand for lots at that price. The auction continues until the price reaches a level where demand for lots is equal to (or less than) supply – the point at which ‘the clock stops’.

Clock auctions are normally used where there are many similar lots which can be effectively allocated as a single category. The clock-sealed-bid hybrid deals with cases where lots being sold simultaneously are too different to be sold together as a single category, and must instead be divided into multiple categories. In each round of the auction, bidders submit a single package bid, in which they link demand across categories (i.e. they bid for their most preferred package at prevailing prices in each round). The auction continues over multiple rounds, with prices rising on lots in those categories where demand exceeds supply. The auction continues until demand for lots in all categories is equal to or less than supply.

The sealed bid is a package bid auction in which bidders bid for specific combinations of pre-determined lots. All bids made in the clock phase roll over into the sealed bid phase. Bids in the clock phase apply to any applicable combination of lots from the associated categories. In addition, bidders that were still active at the end of the clock phase are allowed to augment these bids to reflect their relative preferences between specific lots. The lots are awarded to bidders based on the combination of mutually acceptable package bids with the highest aggregate total.

The relative simplicity of the clock-sealed-bid hybrid compared to the SMRAs with either pure package bidding or augmented switching is a significant strength of this format. However, this simplicity does come at the cost of possible losses in efficiency. In particular, if bidders in the clock phase are only allowed to submit a single bid at each price point, it may not be possible for bidders to express demand for every package of lots that they might want at every price point, and price revelation may be limited. This problem can potentially be overcome by allowing bidders to submit ‘best and final’ offers for all relevant packages of lots whenever they reduce their eligibility in the auction. This variant, which we call the ‘*combinatorial clock auction*’, maintains the simplicity of the clock auction, while achieving the much richer price information associated with an SMRA with package bidding. Efficiency is maintained even with large numbers of categories of lots,

although the opportunity provided to bidders to submit multiple exclusive bids will increase the time required for implementation.

Bidders may also face an exposure risk in the event that there are multiple (generic) lots in a category, but they place significantly different values on lots within the category. This problem can be addressed by increasing the number of categories; indeed, it is possible that every lot could be a category in its own right. However, with large numbers of lots, the auction may then become unduly complex. In effect, the number of categories – or, put differently, the balance between using generic and pre-determined lots in the clock phase – is a matter of judgement, which is closely linked to packaging decisions.

5.6 Timing of the award and impact of spectrum availability

5.6.1 Timing of the auction

With respect to the timing of the auction, there are three issues to be resolved:

- the timing of the availability of the spectrum
- when to schedule the award
- if the award is broken down into more than one auction, how to order them.

From 2008–12, the released spectrum will progressively become available on a regional basis. Although, as discussed in Section 5.3, there is an overwhelming case for awarding released spectrum as national lots, regional release following an early award would at least enable national rights holders to begin rolling out their network. Therefore, there seems no good reason for holding back firms from accessing spectrum that they have won in an auction beyond the point when the incumbent use has vacated the band.

The timing of the award depends on a trade-off between (a) giving bidders maximum time to plan and deploy networks, and (b) waiting for increased certainty over Europe-wide approaches and equipment availability. An award in 2008 would seem to be appropriate. Even though many (perhaps all) bidders for released spectrum are likely to be planning national services, there seems no reason to prevent them initiating network build and even service deployment on a regional basis as soon as spectrum becomes available. Giving

bidders the option to exploit regionally available spectrum during the period of digital switchover seems preferable to leaving the spectrum fallow, and should enable the earliest realisation of economic benefits for consumers. A 2008 date would also allow significant time for existing uncertainties over how the spectrum will be used across Europe to ease, while still enabling the UK to be one of the first countries to make this spectrum available to the market.

We see no case for an award before 2008. Practically, this might be difficult to do anyway, given the complexity of issues to be resolved. For bidders, there would be little advantage in getting the spectrum before 2008, given the long lead time to full national availability.

There is a strong case for having an integrated award of interleaved spectrum and released spectrum (including Channel 36), provided that packaging options and auction design requirements are compatible. If this is not possible, then it would be appropriate to award the interleaved spectrum after the released spectrum. This is based on the fact that interleaved spectrum is generally an inferior substitute to released spectrum. Further, where interleaved spectrum is complementary to released spectrum, it is not necessarily essential to bidders; by contrast, released spectrum typically is essential to such business cases. The auctions should, however, be close together, so as not to prolong uncertainty for bidders whose business plans may be affected by whether they win spectrum in both awards.

5.6.2 Implications of excluding spectrum from the award

The amount of spectrum that will be available for award in an auction has not yet been finalised. It is possible that some of the spectrum may be held back or excluded from the award, for a variety of reasons. Depending on the amount of spectrum that is set aside, this may foreclose or substantially alter some packaging options, and rule out some potential forms of demand. The amount and position of released spectrum available would be particularly important in this respect. Any such changes would likely feed through into auction design, as the choice of auction format is closely linked to the optimal packaging arrangement. In general though, we would expect the broad choice of candidate auction formats to remain unchanged.

6 Assessment of potential market and regulatory failures

The central objective of applying market mechanisms to spectrum allocation is to encourage efficient use of radio spectrum. As the supply of spectrum is scarce, it is not possible to supply all potential services. An optimal allocation is achieved when society is using spectrum in a way that maximises the total value it obtains from spectrum use, which comprises both the value that accrues to individual spectrum users and any external value (e.g. broader social value) that is created.

Market mechanisms for the allocation and assignment of spectrum generally produce optimal outcomes provided that willingness to pay for spectrum is sufficiently closely tied to the value that a spectrum user can generate, where willingness to pay is derived from the bidder's projected profits. An auction will ensure that spectrum will be assigned to those bidders with the highest willingness to pay. Therefore, provided that all bidders' expected profits are closely related to the total value that they can generate, an auction will ensure that licences are assigned to those who can generate most value.

Market mechanisms therefore work well for the *assignment* of spectrum that has been designated for a particular use (provided there are no significant competition concerns or bidder asymmetries). However, when looking at the potential use of market mechanisms for the *allocation* of spectrum to particular uses, the link between willingness to pay and total value may be weaker, especially where the spectrum supports many diverse uses. If the relative willingness to pay of bidders across different uses is not a reasonable reflection of the relative total value that they can generate, then using a market mechanism for the *allocation* of radio spectrum may fail to produce an efficient outcome.

There are three reasons why such a situation may arise:

- *Structural differences* between downstream service markets may lead to differences in the ability of bidders to capture private value, thus distorting their relative willingness to pay as an indicator of total private value.
- *Transaction costs* may drive a wedge between private value and willingness to pay for spectrum.
- There may be significant *external value* associated with some services, which by definition is not reflected in the willingness to pay for spectrum.

In considering the risk of market failure in relation to the award of digital dividend spectrum, it is necessary to consider for each candidate service whether there are any reasons why the willingness to pay of those wishing to provide this service (relative to the willingness to pay of those providing other services) might not properly reflect the total value that would be generated by that use (relative to other potential uses).

Identifying the potential for market failure does not in itself provide justification for regulatory intervention. The ‘cost’ of a market failure is the welfare loss suffered as a result of markets failing to produce the efficient outcome i.e. the difference in value between the efficient service and the next best alternative. Intervention will be beneficial only if the cost of intervening, including the resource cost of intervention and the risk of regulatory failure, is smaller than the cost of the market failure.

The chapter summarises the more detailed analysis of market and regulatory failure issues provided in Annex E. In Section 6.1, we describe a framework for identifying and analysing potential sources of market failure, and considering potential remedies and associated risks of regulatory failure. In Section 6.2, we apply the framework to consider potential sources of failure in relation to candidate services. Where there is a material risk of market failure Ofcom would need to investigate further the costs or intervention in order to assess whether there may be a case for regulatory intervention. Section 6.3 provides a brief conclusion.

6.1 Our approach

In conjunction with Ofcom we have developed a four-step framework for analysing sources of market failure, potential remedies and associated risks of regulatory failure. The framework, which is applicable to any spectrum award, is summarised in Exhibit 6.1 below. In brief, the four steps are:

- *Step 1 – Identify sources of market failure* on a service-by-service basis in relations to: structural differences, transaction cost or external values. The focus here should be any factors that might potentially lead to differences across services in the relationship between willingness to pay for spectrum and total value generated.
- *Step 2 – Assess risk and magnitude of market failure* in order to identify those failures that could be significant enough to justify intervention, taking into account both the probability of such a failure, and the likely impact it might have.
- *Step 3 – Identify forms and costs of intervention* that might be deployed to remedy those failures. Such remedies include: changes to the design of award processes such as specific forms of spectrum packaging; more extensive interventions to correct asymmetries between services or bidders such as bidder credits or subsidies; and reductions in the role of the market in the allocation or assignment of spectrum, such as designating spectrum for particular uses or awarding it without recourse to a market mechanism. It is important to rank the remedies on the basis of the likely effectiveness of the intervention in addressing the market failure; the consistency with technology and service neutrality; the opportunity cost of intervention; and the cost of intervention on both Ofcom and market participants.
- *Step 4 – Assess regulatory failure risks* such as those arising from the intervention failing to achieve the desired effect or having unintended consequences that lead to losses of total value elsewhere or over time. These failures relate to the uncertainty that exists with regard to the impacts of both the potential market failures and the remedies, and also the limitations inherent in the regulatory process resulting from restrictions on the design of potential remedies.

Having completed these four steps, it should be possible to determine whether, starting from the presumption that market-based mechanisms for the allocation and assignment of spectrum are most likely to produce efficient outcomes, there is a case for intervention, and what form such intervention should take.

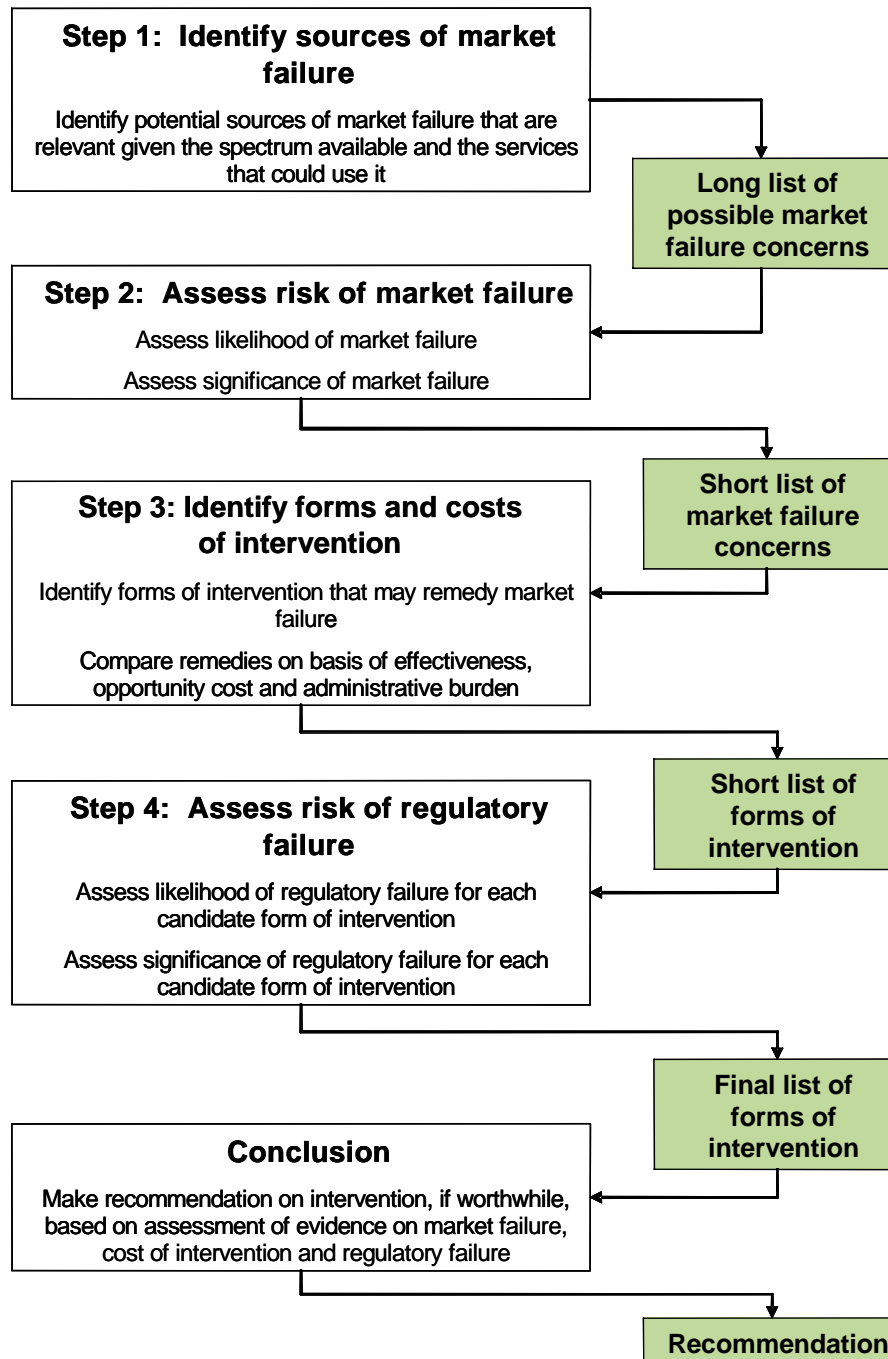


Exhibit 6.1: Proposed decision tree for assessing market failure risks for spectrum award

6.2 Potential sources of market failure in relation to the award of digital dividend spectrum

We have conducted an extensive analysis of potential sources of market failure across all the candidate services. These sources can be grouped into the following categories:

- Competition and market structure:
 - significant differences in market competitiveness
 - limited ability to extract consumer willingness to pay
 - reduced private value and willingness to pay for spectrum due to regulatory obligations.
- Transaction costs and information deficiencies:
 - demand aggregation risks
 - aggregation risks relating to packaging of spectrum
 - uncertainty facing bidders.
- External values:
 - broader social values
 - universal access issues
 - investment spillovers
 - network externalities relating to platform attractiveness
 - network externalities relating to spectrum harmonisation and equipment availability.

In the following subsections, we explore these potential sources in turn, in each case assessing their relevance to particular candidate services.

6.2.1 Competition and market structure

Significant differences in market competitiveness

If bidders do not face similar competitive conditions in downstream markets, either because of scarcity of suitable spectrum or due to other entry barriers, the resulting relative willingness to pay for spectrum across bidders may skew the award in favour of those that

anticipate having market power. This is a potential market failure, as it may result in too much spectrum being awarded to services where providers have market power, even when these provide little total value.

Our assessment suggests that differential competition is unlikely to be a major concern across the potential uses of digital dividend spectrum. Most of the candidate services – probably all of them – operate or will operate in broadly competitive markets. Therefore, there is no reason to expect willingness to pay for spectrum to be unduly inflated by expectations of monopoly profits, or for bidders to attempt to buy excess spectrum so as to foreclose additional entry.

Limited ability to extract consumer willingness to pay

Willingness to pay for spectrum is linked to the private value generated from spectrum use through the prices paid by end users for the services. The ability of spectrum users to extract such value is thus a crucial determinant of their willingness to pay, and significant differences in this ability, for example due to differences in the ability to price discriminate or different funding models across services, would be a potential cause of concern. Translating this into a spectrum auction context, variations in price discrimination and funding models would affect the ratio between profits and total value generated and could lead to market failure.

Pay TV, mobile TV, wireless broadband, cellular mobile and PMSE provided on a commercial basis all provide some scope for both pricing of services and price discrimination between customers. While it is unlikely that their ability to price discriminate (and thus the ratio of willingness to pay for spectrum relative to private value) will be precisely the same for all of these industries, it seems reasonable to suppose that they will not vary so greatly as to compromise the efficiency of a spectrum auction.

By contrast, broadcasters may choose – or in a few cases be required to – offer their channels free-to-air. There could be a concern that the willingness to pay for spectrum may be a smaller proportion of total private value for incremental DTT capacity compared to other services. For free-to-air DTT, the dependence on advertising revenues rather than subscription revenues means that willingness to pay for spectrum will not reflect private

value in the same way as subscription-based services. On the other hand, broadcasters with a strong public service remit may be more prepared to take account of the value they generate for their viewers than commercial broadcasters focusing purely on additional advertising revenues. The results of our modelling are ambiguous on whether there could be a significant difference in willingness to pay proportions for free-to-air DTT relative to candidate services using subscription-based models.

The ability of a PMSE band manager to extract the full value of PMSE use may also be limited, largely because of the problems that would arise in terms of co-ordinating the demand of PMSE users, and in particular obtaining contributions from community users (which are discussed further below). Furthermore, the existing model for funding – which relies on administrative fees that bear little relation to the opportunity cost of spectrum use, is not viable in an auction context. If a band manager were to participate in a spectrum auction on this basis, it is likely that it would not win as much spectrum as it should based on the private value generated by the industry.

Reduction in private value due to regulatory obligations

Since regulation may alter the private value associated with service provision, for example through a change in cost which feeds through to prices, or via a change in quality which impacts on consumption, it may also affect the producer's willingness to pay for spectrum. Although regulation may be introduced to address concerns that the market will not produce the maximum value for society in a technology-neutral spectrum award, existing regulations designed to address market failure concerns in a specific downstream market may have the effect of inhibiting producers from that industry from competing for spectrum with less-regulated industries.

None of the prospective users are likely to face coverage or content requirements linked directly to their use of digital dividend spectrum. However, in the case of DTT, the public service broadcasters are already under obligations in relation to programming content as well the coverage they have to achieve – for example, the amount of news that they show, the originality, diversity and impartiality of their content, and the proportion of UK productions broadcast.

Our assessment suggests that the burden of existing regulations on PSBs is unlikely to be sufficient to cause a market failure in the auction. However if new constraints were imposed, their ability to compete for spectrum may be compromised to the extent that this is not offset by other intervention such as special funding treatment.

6.2.2 Transaction costs and information deficiencies

Aggregation risks relating to packaging of spectrum

Some bidders may require multiple lots but have different patterns of synergies between them, for example arising from economies of scale and scope and requirements for paired spectrum. Therefore, depending on how the spectrum is packaged, aggregation risks may be present which will depress bidders' willingness to pay. If certain bidders face higher aggregation risks, their willingness to pay will be disproportionately depressed, resulting in market failure.

Aggregation risks are a significant concern for this award, given the very wide range of candidate uses and their conflicting demands for spectrum. Two uses in particular – DTT multiplexes and cellular mobile – have particularly complex requirements. However, the risk of market failure depends on the likelihood that a candidate use facing potential aggregation risks actually has the highest value. Our assessments suggest that additional DTT and mobile TV are amongst the leading candidate uses for this band, which suggests that we should pay particular attention to their requirements in packaging and auction design. Wireless broadband is also a strong candidate. By contrast, we have found little evidence of current demand for this spectrum from cellular operators, implying that if a level playing field is impossible between all potential services, priority should be given to packaging and auction rules that favour the services which are perceived as most likely to generate the highest value.

Demand co-ordination

Some bidders may require only a small proportion of an available lot, whether on a frequency, location or temporal basis. Such bidders are most unlikely to be able to compete

in an auction for a lot by themselves, as the value they place on a portion of one lot is very unlikely to outweigh that of another user that can utilise the whole lot. One solution is to identify other users with complementary demand, and aggregate this demand. However, this creates a co-ordination challenge, given the search and transaction costs. If these costs are too high, then the willingness to pay of such a coalition will be deficient and the market may fail to allocate sufficient spectrum to the service.

Problems in co-ordinating demand amongst multiple users potentially apply to PMSE use, local TV and home networks. Our assessment suggests that while there is scope for a PMSE band manager operating on a commercial basis to co-ordinate demand from professional users effectively, the disparate nature of community users suggests that any attempt to co-ordinate their spectrum use would be expensive and might not be worthwhile. Therefore, whilst the risk of market failure due to co-ordination problems may be low for professional PMSE use, there is a substantial risk of market failure in relation to provision of spectrum for community PMSE use.

In relation to local TV, given that spectrum will only be required in a localised area, if spectrum is sold on a national basis, a single local TV broadcaster would be poorly placed to win access. There is a clear need to co-ordinate with other users. However success in a spectrum auction is not an all-or-nothing outcome in relation to local TV provision on DTT. Even in the presence of market failure, scope for partial success in a spectrum auction or secondary market trading may cap the downside risk.

The business model for home networks is based on home users buying their own equipment and deploying their own networks with no centralised provider. Such use is inherently unsuitable for participating in a spectrum auction, as it is virtually impossible to co-ordinate the demand of users in such a way that the value they place on the service could be expressed in the form of willingness to pay for spectrum in an auction. Therefore regarding the deployment of home networks, it would seem reasonable to assume that any such use would require a decision to make available some of this spectrum on a licence-exempt basis.

Uncertainty

Uncertainty can be a source of market failure when different spectrum users face different degrees of uncertainty over the commercial prospect of their services, or if their attitudes towards risk differ. Uncertainty over future commercial prospects exists for all candidate services, but is particularly relevant for those for which the market is small or non-existent, such as mobile TV services, local TV or wide-area wireless broadband.

Our assessment suggests many of the potential inefficiencies that can arise from uncertainty over future costs and benefits may be most effectively addressed through secondary trading or a change in spectrum use. It would not seem appropriate to postpone any award of digital dividend spectrum until the commercial prospects for some of the current candidate services become clearer. Even though the future development of services that are currently novel may become clearer over time, there may be further innovation and newer, as of yet unknown, services which would be in a similar situation then as currently new services are today.

6.2.3 External values

Broader social values

Broader social values, as a sub-category of external value, are defined in detail in Section 4.3. Since producers and consumers only take into account the private value of participating in the market, the presence of significant broader social values may result in either under- or over-provision of a candidate service from the point of view of maximising society's welfare as a whole.

Our assessment suggests that while there is some degree of broader social value associated with all the candidate uses, the broader social value associated with incremental provision of these services using digital dividend spectrum, is significantly smaller for most services. However, the research did identify some possible concerns related to HDTV, local TV and PMSE. For example, our research suggests that HD is currently widely perceived as a luxury service, and as such would generate little broader social value, but this assessment could change if HD subsequently develops into a mainstream service. Meanwhile, there are

concerns about how much of the perceived benefits of local TV will actually be realised, given that local TV must compete with other content.

Universal access in response to broader social value considerations

Universal access to certain types of communication service is considered advantageous to society. The benefits it brings, in terms of, for example, education or health and safety, are examples of externalities. However the presence of these external benefits of universal access creates the possibility of market failure in a spectrum auction if they exist disproportionately for one service compared to other services competing for use of the spectrum. Unless these benefits are taken into account, a bidder may be outbid by an alternative use, even though the bidder's use would generate the highest total value.

It is apparent that UK citizens currently perceive the external benefits associated with universal access to digital television and broadband to be larger than those associated with other candidate uses. However, this would only be a concern for a spectrum auction if digital dividend spectrum is likely to play a key role in realising these benefits. In practice, there are significant grounds for scepticism on this point, given that any deployment of TV or broadband in digital dividend spectrum would be incremental to services using other spectrum and platforms.

Most of the broader social value derived from universal access to digital television is derived from PSB channels, which already have extensive provision on existing DTT spectrum, sufficient for them to reach 98.5% of UK households. With the exception of local TV, the incremental services that could be provided using digital dividend spectrum were seen as having low broader social value in our survey work. However, in relation to the possible transition to HDTV, there may be concern about the knock-on impact on the number of PSB or other services available.

Based on our research, it appears that the benefits of universal access to broadband primarily derive from the high-speed data attribute of the service rather than wireless connectivity, and our analysis suggests the likelihood of market failure in a spectrum auction is therefore rather low. As the incremental broader social benefits from deploying wireless broadband using digital dividend spectrum appear modest, it follows that the risk

that wireless broadband will be outbid for spectrum by a service with lower total value is also modest.

Investment spillovers

Investment spillovers occur when investment in the provision of a particular good or service has a positive impact on other sectors. Differences in investment spillovers across services could lead to an auction failing to allocate spectrum to the use with the highest total value. For example, if services and terminal equipment are provided by separate agents, the benefits associated with the boost in demand for equipment will not be reflected in the benefits associated with the increased use of a service, and thus will not be fully reflected in the willingness to pay for spectrum.

Spillover effects, such as these complementarities between the service provided and the equipment necessary to deploy it, could in principle apply to some extent to all the possible uses of the spectrum. Arguments have been made suggesting that they are particularly large in relation to PMSE, HDTV and local TV.

However, our assessment suggests that the external benefits accruing from investment spillovers owing to complementarities are more limited than might appear at first sight, and that they are not likely to create significant differences between private and broader social values. There are no grounds to believe that HDTV or local TV offer disproportionate investment spillover benefits relative to other uses, and most of the perceived spillover benefits associated with PMSE appear to be components of the private value chain, rather than externalities. We therefore find no significant evidence to suggest that there could be market failure due to the presence of investment spillover effects.

Network externalities relating to platform attractiveness

Network externalities arise when market participants make decisions based on comparisons of private benefits with private costs, ignoring the effects that their decisions have on other market participants. This may lead to a network being too small or too large from the point of view of other producers or consumers. If the value of network effects are not

internalised by any party, their presence constitutes a network externality which will not be reflected in willingness to pay for spectrum at the auction stage. If these effects are large enough, they could lead to market failure.

One such source of network externality occurs when potential spectrum users do not consider the benefits to others of increasing the attractiveness of the platform. For example, the decision by one producer to introduce new content and/or to facilitate additional content by expanding capacity may bring benefits for all producers, and certain decisions over capacity and content made by a few producers may ultimately determine whether the platform is a success or failure.

Our assessment suggests that there are two services where this type of network externality is likely to be present: (a) mobile TV and (b) DTT in the case that HDTV emerges as a key source of additional value for viewers. If these effects are large enough and cannot be internalised by bidders in an auction, they could result in market failure in an award process. This seems rather unlikely for mobile TV but may be more plausible for HDTV:

- In the case of mobile TV, there will likely only be a small number of providers. This makes it much easier for potential bidders for spectrum to anticipate positive network externalities resulting from the activities of their competitors and to internalise them within their bids. Non-internalised network externalities are unlikely to be so large that they would distort an auction.
- The same is not necessarily true in the case of HDTV. Here, there are a large number of broadcasters and greater scope for network externalities to be unequally shared amongst them. In considering the willingness to pay of broadcasters for new spectrum for HD provision, there appears to be a real possibility that this may be deficient because of the presence of network externalities. However countering this is the fact that the most likely initial bidders for HD capacity (BBC, ITV and Channel 4) are also the largest providers of channels on Freeview, so there is some scope for these companies to internalise network externalities.

Network externalities relating to spectrum harmonisation and equipment availability

Another source of network externality stems from producers not considering the benefits to others from harmonisation of spectrum use and associated equipment. These effects may arise where there are a number of producers that offer a similar service, but there is a choice over the available technology. In this case, a decision by an operator to adopt the same technology as a rival may benefit both producers if economies of scale in provision lower costs. However, the producer that makes this decision will only consider the benefits to itself, thereby potentially contributing to a market failure if the network externalities accruing to other producers are large enough.

Economies of scale in equipment are particularly relevant to mobile TV, cellular mobile and wireless broadband. In generating these economies, mass deployment across multiple European countries is more important than at the UK level and therefore we are not concerned about the ability of bidders to second-guess the technology decisions of their immediate competitors. Instead, expectations about deployment of their service using UHF spectrum in other countries and the availability of equipment matter more.

Our assessment suggests that network externalities related to equipment will probably be modest across all services, at least within the UK. There may be market failure risks in relation to uncertainty over the future cost and availability of equipment, particularly for cellular mobile, because take-up and deployment of similar services abroad using UHF spectrum may be unknown at the time of any UK auction. However, it is unlikely that the effect of uncertainty could be sufficient to prevent an auction functioning efficiently. For the leading candidate services, such as mobile TV, it seems likely that the market will be able to resolve much of the uncertainty over equipment cost and availability ahead of an auction, and it is unlikely that regulatory intervention would be able to improve the situation.

6.3 Conclusions

We have set out a framework for the assessment of market failure risks, and the decision whether, and if so how, to intervene in response to this. Based on the premise that the market mechanism is the best way to achieve efficiency in the award process, and ensuring

that total value generated from spectrum use is maximised, the case for intervention needs to be based on an assessment of the likely welfare loss from market failure on the one hand, and the cost of intervention on the other. This cost also has to include the potential detriment that arises from the risk of regulatory failure.

We have also considered reasons for market failure in relation to the award of digital dividend spectrum. Overall, we find that there are a number of reasons why the ratio of willingness to pay for spectrum to total value generated by the candidate spectrum uses may differ. This is not surprising given that the digital dividend spectrum is potentially usable for a wide range of services with fundamentally different characteristics.

However, there is no strong evidence with regard to the magnitude of these effects. Though some candidate uses, such as PMSE and free-to-air DTT (including HDTV and local TV) appear more likely to be subject to market failure risks, there is no conclusive proof that intervention is necessary. Additionally, before reaching any view on the appropriateness of intervention it would be necessary to consider the available remedies in order to identify the likely opportunity cost of intervention and the risk of regulatory failure.

