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Spectrum award – 3.6 GHz band.

Report from DotEcon on the design of an award process for assigning rights of use for frequencies in the 3.6 GHz band

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Design of an award process for assigning rights of use for frequencies in the 3.6GHz band

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Executive summary

Spectrum available for award

1. ComReg had previously considered including the 3.6GHz band in a combined award with the 2.6GHz band and possibly other bands. However, ComReg is currently proposing to award the 3.6GHz band in a self-standing process.

2. There is little reason to include any of the other bands (2.3GHz, 1.4GHz or 700MHz) that were considered for inclusion in the 2.6GHz award in an award of 3.6GHz spectrum. These other bands are likely to interact more strong with each other and the 2.6GHz band (whether by being substitutes or complements) than with the 3.6GHz band.

3. The spectrum available for award in the 3.6GHz band forms two contiguous blocks: 325MHz (from 3435MHz to 3475MHz) above state services and 25MHz (from 3410MHz to 3435MHz) below. Because of the large amount of contiguous spectrum available, we would expect significant demand. However, the mix of demand from different types of potential users is uncertain. It is possible that the band could accommodate a number of licensees with a variety of different uses.

Regional licensing

4. A 2008 EC Decision required all Member States to make the 3.6GHz band available for fixed, nomadic and wireless access systems. However, the existing FWALA (and subsequent BWALA) licensing scheme for 3.6GHz spectrum is not appropriate for mobile and nomadic applications. ComReg set an end-date of 31 July 2017 for this scheme.

5. At consultation, some respondents expressed interest in licensing 3.6GHz spectrum on a regional basis. It is feasible to use regional licences provided that:

   - the licence areas are not too small, as this would lead to excessively complexity both for the auction implementation and for bidders in valuing the various options;
   - a combinatorial auction is used that allows for recombination of regions by bidders seeking a

larger footprint without the risk of winning an unworkable subset of their target lots ('*aggregation risk*').

6. ComReg has proposed two options for regionalisation with either five regions or, by breaking out further urban centres, nine regions. Neither option leads to an unworkable number of possible footprints. In the first case, there are just 31 possible combinations of regions. In the second case, there are 511 possible combinations, but at most 421 of these are likely to be of commercial relevance for bidders forming a logically coherent footprint. We consider both possibilities to be quite workable within a combinatorial auction format.

7. We cannot realistically expect to have a pattern of regions that exactly meets all bidders' requirements. Using a fine pattern of subdivision would provide more flexibility for bidders to determine their footprints, but leads to an exponential increase in complexity, both for the auction implementation (in terms of solving for winners and prices in a combinatorial auction) and for bidders (in terms of the number of potential packages of lots they may need to consider and value). Therefore, we recommend that ComReg does not subdivide regions further than its current proposals. As a rough rule of thumb, in excess of 10 regions would create too much complexity.

8. If the geographical extent of regions does not exactly match bidders' requirements, there are opportunities for bidders to bid as consortia or to use secondary transactions, such as transfer of part of a licence coverage area, or leasing arrangements. Nevertheless, it is important that we do not rely too heavily on the potential for secondary transactions – given that there are various impediments that may prevent them occurring – and try to ensure that the award mechanism is as efficient as possible in its own right.

Lot sizing

9. In order to provide maximum flexibility to bidders, we recommend that the 325MHz above state services be offered as sixty-five 5MHz blocks. It is possible to somewhat simplify the auction design by using larger lots (say 10MHz or 20MHz); however, in the context of a combinatorial auction with a regional structure, the

reduction in complexity is modest relative to the loss of flexibility for bidders in determining the amount of spectrum they want. Because it is implausible that the 25MHz below state services could be efficiently shared by two or more licensees, we recommend that for simplicity this be offered as a single lot.

Competition concerns

10. It is unlikely that any significant concerns about competition in downstream markets could arise as a result of allocation of spectrum in this band. Nevertheless, it would still be prudent to impose a safeguard cap to limit prevent a single winner gaining so much spectrum that it would be in a highly asymmetric position relative to other winners. We suggest that a cap in the range of 150MHz to 240MHz on spectrum won in this band would serve this purpose.

Auction design choices

11. With regional licensing and spectrum offered in 5MHz blocks that can be recombined to suit users' needs, a combinatorial auction format is ideal for this award. In particular, we would recommend the use of a combinatorial clock auction (CCA). ComReg has previously used a CCA for the Multi-Band Spectrum Award (MBSA) in 2012 and similar rules could be used here (though some of the complications of the MBSA arising from renewing expiring licences would be avoided).

12. The CCA is a multiple round auction in which bidders state how many lots they want at prices posted by the auctioneer. Round-by-round, prices are increased for lots in excess demand. Once demand has been reduced to no more than supply, as further round of bidding – a supplementary bids round - allows bidders to increase bids already made (within limits) and bid for other alternatives. Bids are always made for packages of lots that are never split, so bidders do not face aggregation risks. Once all bids are in, the auctioneer optimises the total value of winning bids, selecting at most one winning bid from each bidder. Prices are determined on an opportunity cost basis.

13. With a CCA, lots would be grouped into a number of categories. For each region, there would be a category of 65 generic, frequency independent 5MHz lots above

state services and a second category consisting of a single 25MHz lot below state services.

Reasons to use a CCA

14. We also consider a number of other candidate auction formats, including a sealed bid combinatorial auction (similar to the 26GHz award run by ComReg in 2008), a simple clock auction and a simultaneous multiple round ascending (SMRA) auction.

15. The CCA has a number of advantages for this award over the alternatives:

- By eliminating aggregation risks, it provides a mechanism by which bidders seeking to aggregate regions can compete fairly with those wanting a sub-national footprint. It also allows bidders to assemble larger contiguous blocks of frequencies likely to be needed to deploy high bandwidth services efficiently;
- It allows bidders to switch freely between various alternatives on the basis of relative prices;
- It avoids creating strong incentives for bidders to moderate their demands to seek a lower price ('*strategic demand reduction*') that can arise in an SMRA or clock auction;
- The structure of open rounds provides information for bidders to solidify their own valuation estimates (reducing common value uncertainty) and also understand which packages are likely to mesh with the demands of other bidders and are relevant to bid for (significantly reducing complexity). Both benefits would be absent from a sealed bid combinatorial auction;
- Although not entirely immune to gaming, the CCA would be more robust than an SMRA or clock auction, both of which may create rich gaming opportunities once there is a regional lot structure.

Managing complexity

16. The computational burden of computing winners and prices is a potential problem for combinatorial auctions, including the CCA, once the number of theoretically possible packages becomes too great. Although the number of combinations of regions is modest in either of ComReg's options for regionalisation, there is also a large amount of spectrum available (66 lots in total).

Once the possibility of bidding for various amounts of spectrum in the different regions in taken into account, the number of possible packages is vast.

17. Computational complex can be easily controlled in practice by limiting the number of distinct packages for which a bidder can bid (say to 1000 or so). However, it is then important that bidders can determine which packages they might have some chance of winning if they are to deploy this limited number of packages effectively. By using a CCA with the activity rules used for the MBSA (i.e. a final price cap for supplementary bids and relaxed activity rules for the clock rounds), the clock rounds can be informative about potential winning packages.

Assignment round to determine frequencies

18. Frequency assignment for the lots above state services would be determined through a follow-up single-shot sealed-bid assignment stage. Bidders would be guaranteed to receive all generic lots above state services in a single contiguous frequency block. Where bidders won the same amount of spectrum in a number of regions, they would receive the same frequencies in these regions. Where there are multiple options remaining, bidders would make bids reflecting their relative preferences for different frequency combinations across regions. The mutual compatible combination of these bids of greatest total value would win, with prices determined by opportunity costs.

1 Introduction

19. ComReg is considering awarding usage rights for spectrum in the 3.6GHz band in a self-standing process. Initially the 3.6GHz band had been considered for inclusion, along with various other bands, in the 2.6GHz award.[1]

20. As part of this process, ComReg has asked DotEcon to assess:

- whether it may be appropriate to also award any other bands previously identified for inclusion in the 2.6GHz award in the 3.6GHz award;
- the design options for a competitive award process for the 3.6GHz band; and
- the implications of offering licences on a regional, sub-national basis.

Objectives

21. The award should meet ComReg's overarching objectives to promote competition, encourage development of the internal market and to protect interests of consumers.[2] Auction design also ought to encourage the efficient use of spectrum.

22. In practical terms, these objectives mean that the award process should prioritise achieving an economically efficient outcome. Typically, this can be achieved by assigning spectrum to the users with greatest value. However, in certain circumstances it may be appropriate to adopt provisions to avoid excessive concentration of spectrum holdings if this could suppress competition in the downstream markets.

[1] See ComReg Document 14/101 and ComReg Document 14/102 for DotEcon's Report.

[2] Communications Regulation Act, 2002 as amended.

Spectrum available in the 3.6GHz band

23. There is a total of 400MHz of spectrum in the 3.6GHz band, but it is expected that only 350MHz will be made available for award as:

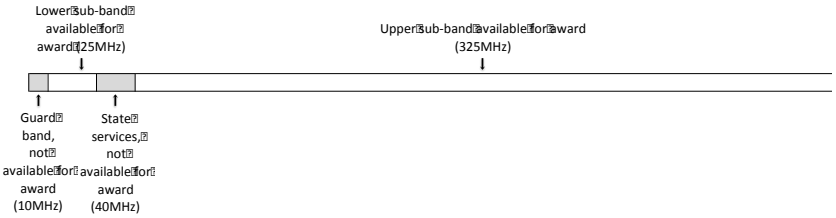
- 40MHz of spectrum (from 3435MHz to 3475MHz) are used for state services, which are expected to continue for the foreseeable future; and
- the lowest 10MHz in the band (3400-3410MHz) is expected to be used as a guard band.[3]

24. Therefore, the frequencies available for will be in two separate blocks:

- 25MHz below state services, running from 3410MHz to 3435MHz; and
- 325MHz above state services, running from 3475MHz to 3800MHz.

25. The resulting band plan is illustrated in Figure 1. Although this spans frequencies from 3.4GHz to 3.8GHz, throughout we will refer to this as the 3.6GHz band.

Figure 1: Availability of spectrum in the 3.6GHz band



Potential inclusion of other bands in the same award

26. In ComReg document 14/102, we assessed the degree of substitutability and complementarity between all the bands (700MHz, 1.4GHz, 2.3GHz and 3.6GHz) considered for inclusion in the 2.6GHz award. Based on our assessment of the degree of interrelation of the demand for these different bands, we concluded that it would be appropriate to include all these bands in the 2.6GHz

[3] See ComReg Document 10/55.

award on the grounds that they could potentially be either complements or substitutes for spectrum in the 2.6GHz band. We noted that the 3.6GHz band may potentially be less substitutable with the other mobile capacity bands (primarily 2.3GHz and 2.6GHz), but still considered that it might be advantageous to award these bands simultaneously to allow bidders to substitute between them if desired.

27. However, while the proposal to include the 700MHz, 1.4GHz and 2.3GHz bands in the 2.6GHz award had general support, the responses to the consultation on the 2.6GHz award suggested that whilst the 700MHz, 2.3GHz, 2.6GHz and possibly also the 1.4GHz band might have valuation interrelationships, the 3.5GHz band was less strongly interrelated. Indeed, a number of respondents to the consultation noted their preference for the 3.6GHz band to be sold separately.[4]

28. The responses to the consultation suggest it may be appropriate to award the 3.6GHz band in a separate process. Furthermore, we do not see any strong grounds for also carrying across other bands proposed for inclusion in the 2.6GHz award into the 3.6GHz award process. In particular:

- The consultation responses did not suggest that the other possible high frequency bands – primarily 2.6GHz and 2.3GHz – are as close substitutes for 3.6GHz as they are for each other. Indeed for some classes of user – such as an operator seeking a large amount of contiguous unpaired spectrum – the 3.6MHz band may have few short-run alternatives;
- The 700MHz band is potentially complementary to higher frequency spectrum (for example, if an operator wants to combine spectrum to provide coverage and capacity). However, again the stronger interaction is likely to be between 700MHz and the 2.6GHz and 2.3GHz bands, in that these bands are all attractive for mobile services, rather than with 3.6GHz.

[4] See ComReg Document 15/15.

29. Overall, we consider that including other bands would be likely to increase the complexity of an award for no clear benefit, especially that it is already complicated by the relatively large amount of spectrum available in the 3.6GHz band and that it may be offered on a regional basis, as discussed below.

Current use of the 3.6GHz band

30. Part of the 3.6GHz band is currently used for the provision of fixed wireless services under the fixed wireless access local area (FWALA) licensing scheme, which was introduced in 2003. The FWALA scheme facilitated the provision of wireless broadband services in small towns and rural areas, while also providing additional competition in urban areas. However, licences issued under this scheme expire on 31 July 2017.[5]

31. FWALA licences provide rights of use for a specific channel within a local area defined by:

    (i) a geographic coordinate (specified by the licensee upon application); and
    (ii) a radius of 20km around that coordinate.

    FWALA licences were issued for a year, and could be renewed up to a maximum of seven years.

32. The interest in FWALA licences grew substantially since inception of the scheme, leading to an increase in both the number of licensees and the number of licences held by each licensee. Between 2003 and 2010 ComReg released several other tranches of 3.6GHz spectrum under the FWALA scheme in response to demand.

33. In 2008, the European Commission issued a Decision that requires all Member States to designate and make available the 3.6GHz band for fixed, nomadic and mobile wireless access systems.[6] In response to this requirement, ComReg set an end date for the FWALA

[5] These frequencies were offered alongside 10.5GHz and 26GHz frequencies.

[6] Commission Decision 2008/411/EC.

scheme of 31 July 2017. This end date aligns with the latest expiry date (if renewed for the maximum of seven years) of the last licences awarded under the FWALA scheme. In July 2010, ComReg published a consultation on the introduction of mobility to the 3.6GHz band.[7] Following this consultation, in January 2011, ComReg adopted a two-stage process for implementing mobility in the band:[8]

- for the first stage, ComReg adopted a broadband wireless access local area (BWALA) licensing scheme, which runs in parallel with the FWALA scheme until 31 July 2017;
- from 1 August 2017, a new licensing scheme would replace both the FWALA and the BWALA schemes.

34. The broadband wireless access local area (BWALA) adopted the same geographical coverage definition as the FWALA scheme. BWALA licences permit the use of mobile as well as fixed wireless access systems, and are subject to slightly higher fees than FWALA licences to reflect their more liberal usage conditions. Along with the introduction of the BWALA scheme, ComReg also set out a process for upgrading FWALA licences to BWALA licences. However, ComReg has not received any applications for BWALA licences or for upgrading FWALA licences to BWALA since this option became available in 2011.

Potential demand

35. The 3.6GHz band may be of interest for a wide range of potential users, including current FWALA licensees, mobile operators and others wishing to provide high-bandwidth nomadic services. We can expect significant demand for usage rights in this band, as it can provide access to a much larger contiguous block of spectrum than other bands at similar frequencies likely to be available in the near future. However, the nature of

[7] ComReg document 10/55.

[8] ComReg document 11/03

participation and competition in the auction is difficult to forecast. In this context it is appropriate to use an auction to assign usage rights for the available frequencies, as this allows interested parties to express their various needs. However, for the auction to lead to an efficient assignment of the spectrum it is important that it makes spectrum available for quite different operators in a technology-neutral manner.

36. While the band is already used for fixed wireless access services, it may also be suitable for other applications. For instance, while the 3.6GHz band has not historically been a core mobile band, there are current strong moves towards harmonisation for TDD-LTE use. Moreover, making available such an unprecedented amount of spectrum in a single contiguous band may provide a good opportunity for high-bandwidth applications, such as short-range cells and urban capacity and may create opportunities for players other than the traditional mobile operators. The award process should not foreclose any of the various possibilities.

Regional licensing

37. In ComReg document 14/102, we discussed the possibility of awarding at least some of the 3.6GHz spectrum on a sub-national basis. Some existing licensees may not require national coverage; therefore, making usage rights available only as national coverage licences could have some undesirable consequences:

- Operators interested in using the spectrum on a sub-national basis who acquire a national licence might leave frequencies unused in areas outside its target region at the same time that other regional users might have been willing to operate in those areas. Whilst appropriate secondary trades might remedy this situation, these could involve many parties and be difficult to co-ordinate. Therefore, there is benefit in trying to ensure that spectrum is efficiently assigned in the first instance without unnecessarily relying on secondary transactions.
- Nationwide licence conditions and coverage requirements (if applied) could depress the value of a national licence for regional users if it forces them

to deploy a wider network than they need. Indeed, such conditions might make it unviable for a regional user to acquire a national licence even if it anticipated sharing the licence geographically with other users. This could significantly increase the challenges faced by regional bidders and possibly reduce participation in the auction.

38. It is possible that the desired footprint of some regional users of 3.6GHz spectrum could be complementary to that of a national operator only wishing to acquire spectrum for capacity in specific high-traffic spots in some urban areas. Offering some licences on a regional basis would provide an opportunity for such users who have no need for a national licence to express their demand. This would allow for outcomes where national and regional operators share frequencies geographically without the need for such operators to enter a sharing agreement (either prior to bidding or after the auction). This may promote more efficient use of the spectrum relative to a situation where such users might need to compete against each other for nationwide usage rights, especially if such operators fail or are unable to enter a sharing agreement after the award.

39. As part of their responses to ComReg's related consultation (ComReg document 14/101), several respondents (including both MNOs and FWA operators) expressed a view that at least some of the spectrum in the 3.6GHz band should be made available as regional licences. However, while the approach to establishing geographic coverage under the FWALA scheme may be appropriate for the localised needs of fixed wireless operators, it would have serious limitations for operators wishing to offer mobile or nomadic uses:

- first, a coverage area of 20km radius is likely to be insufficient for mobile services, and thus any operator wishing to offer such services might

require several local area licences to achieve greater coverage;[9]

- second, the FWALA and BWALA schemes only guaranteed a relatively short licence duration, which may be insufficient for operators to recoup the investment needed for a network; and
- finally, the current approach could create coordination and interference issues, and complicate expansion of licensees' footprints.

40. Licensing the 3.6GHz band in line with the Decision of the European Commission to allow fixed, nomadic and mobile wireless access systems is incompatible with this localised licensing approach, in that it is difficult to acquire rights of use for a sufficiently large footprint to provide coherent services and for a long enough time to provide reasonable investment incentives to suppliers. Nevertheless, this does not preclude offering regional licences in a different form if this is appropriate to meet different bidders' requirements. Conventional auction designs involve defining a number of non-overlapping regions, with bidders able to bid for a number of lots to express their desired footprint. By offering licences regionally but at the same time within a single award process, bidders can also aggregate licences into a larger footprint. A regional licencing scheme based on pre-specified regions and in which licences have a common expiry date would also simplify spectrum management of the band. Therefore, it is possible to accommodate the requests for regional licensing provided an appropriate auction design is used so that all interested parties can express their demand on a level playing field.

[9] The FWALA and BWALA schemes allow operators to their expand coverage into a Geographical Service Area (GSA) by acquiring multiple overlapping licences. However, extending coverage may difficult under the BWALA scheme, as usage rights in nearby areas may have already been granted to other operators.

Role of secondary transactions

41. Various forms of spectrum transfer are permitted in Ireland, including the straight transfer of a current licence to another party and subdivision of a licence by geographical area and/or frequency. Short-term leasing arrangements, not resulting in a formal transfer, are also possible.

42. Such possibilities for secondary trading are helpful, as they provide a backstop to remedy any inefficiencies that might arise from the primary assignment of spectrum. However, secondary trades may fail to occur because of bargaining inefficiencies (where each side pushes too hard and a deal fails to be struck even though it might be mutual beneficial), coordination failures (where an efficiency improvement might involve many parties) or transaction costs (which can reduce the net benefits from the trade and discourage some transactions).

43. Secondary trades (as well as leasing arrangements and spectrum sharing arrangements) may be useful in permitting reconfiguration of spectrum licences. In particular, this may help to accommodate spectrum users with limited, sub-national footprints who may have complementary footprints with other users. However, the possibility of secondary trades should not be relied upon to ensure that spectrum is efficiently assigned and used; there is still good reason to ensure that primary assignment is as efficient as possible. Therefore, the proposed auction design tries to provide a framework in which a variety of different potential users with different geographic footprints can compete and reasonable efficient assignments can be achieved.

Structure of this report

44. This report is structured as follows:

- in Section 2 we discuss key issues when offering the spectrum in the 3.6GHz band on a regional basis, and provide our recommendation for packaging the available spectrum into lots;

- in Section 3 we discuss whether it may be appropriate to adopt any measures to safeguard competition in the downstream market;
- in Section 4 we present our recommendation on auction design, with an assessment of alternative auction formats that might be used for assigning spectrum amongst applicants;
- in Section 5 we briefly outline how a follow-up assignment process could be used to determine the specific frequencies awarded to bidders.

2 Lot structure

45. In line with the technology neutral approach adopted by ComReg, we propose that the available spectrum is broken into the smallest natural blocks (5MHz, at least for spectrum above state services) that can then be recombined as bidders see fit. This provides maximum flexibility to bidders and avoids arbitrary administrative decisions.

46. Although it is difficult to assess potential demand for the 3.6GHz band and the strength of commercial cases for regional licences, consultation respondents have raised the possibility of regional licensing. The auction process can admit this possibility and allow competition between bidders requiring different geographical footprints providing that this does not result in excessive complexity. However, while finer divisions of these regions provide additional flexibility in terms of expressing desired footprints, this also increases the complexity of the auction.

47. ComReg is currently minded to use a regional structure and is considering two different options:

- **Option 1** consists of five regions, namely:
  - *Borders (including Counties Donegal, Leitrim, Cavan, Monaghan and Louth)*
  - *Connaught less county Leitrim and the CSO boundary for Galway City and Suburbs*
  - *Leinster less county Dublin*
  - *Munster less the CSO boundary for Limerick City and Suburbs and Cork City and Suburbs*
  - *Dublin County*
- **Option 2** consists of nine regions, namely:
  - *North West (Counties Donegal, Leitrim, Sligo, Mayo, Roscommon and Galway excluding the Galway CSO City and Suburb region)*
  - *North East (Counties Cavan, Monaghan, Louth, Longford, Westmeath, Meath, Offaly, Laois, Kildare, Wicklow and Dublin excluding) Dublin CSO City and Suburb region.*

- *South East (Counties Kilkenny, Carlow, Wexford, the legal boundary of South Tipperary and Waterford, excluding Waterford City and Suburbs)*
- *South West (Counties, Clare, Limerick excluding Limerick CSO City and Suburbs, Kerry and Cork excluding Cork CSO city and Suburbs and the legal boundary for North Tipperary)*
- *Dublin CSO boundary for City and Suburbs*
- *Cork CSO boundary for City and Suburbs*
- *Limerick CSO boundary for City and Suburbs*
- *Galway CSO boundary for City and Suburbs*
- *Waterford CSO boundary for City and Suburbs*

48. Neither regionalisation scheme creates unmanageable complexity. However, regional licensing is likely to result in aggregation risks for bidders who are targeting multiple regions. Without measures to mitigate aggregation risks, there is a risk of inefficiently fragmented outcomes and distortion of competition between different types of bidder.

2.1 Key issues for regional licensing

49. The 3.6GHz band offers a large amount of contiguous spectrum in comparison with previous awards. It has the potential to be used to deploy high-bandwidth services in either urban or rural areas. Whilst we cannot anticipate the potential demand for 3.6GHz spectrum with any certainty, the design of the award process should not exclude reasonable business cases, but rather create neutral competition between different types of operators, including national and regional operators.

50. Offering licences in a simultaneous award requires a framework where it is possible to assess whether the demands from competing bidders conflict. Some operators (including existing FWALA operators) might want to acquire usage rights to deploy services regionally. At the same time, it is likely that some operators (including FWALA operators with a large

geographical footprint, MNOs and any other bidders intending to deploy services with national reach) may seek to acquire licences with national coverage. It is also possible that existing MNOs might need spectrum for capacity primarily in urban areas only; this could be compatible with there being other users of the same frequencies outside those areas.

2.1.1 Aggregating across regions

51. Aggregation risk arises when there are synergies across lots and the collective value of a number of lots exceeds the sum of the standalone values of the individual lots within the collection. For instance, even if spectrum is offered as regional licences, a bidder could combine these into a larger footprint (including a full national footprint). However, a bidder wishing to acquire licences covering the whole nation may have very little value for licences covering just a few, non-connected regions. If the auction format evaluates bids for regional licences independently of each other, a bidder seeking a number of licences across individual regions is exposed to the aggregation risk of winning licences in only some of these regions.

52. Aggregation risks can compromise efficiency depending on the auction format used. Bidders seeking to aggregate lots are likely to take into account the risk that they may fail to obtain all the lots they seek (and in the extreme end up with an unworkable subset of lots), and hence they may keep bids closer to the value of standalone lots rather than bidding their full complementarity value for aggregations. As complementarities between lots may be underrepresented in the bids received, then there is a risk of excessively fragmented outcomes in which one or more winners fail to win complementary lots. Alternatively, in some auction formats bidders who might otherwise be stranded with an unworkable combination of lots might feel compelled to bid above valuations in order to control their losses.

Offering a mix of national and sub-national licences

53. A possible, if poor, solution is to offer a mix of national and sub-national licences, so that bidders seeking national coverage may bid for national licences to suppress aggregation risks. However, this would require ComReg to judge an appropriate split of the band between national and sub-national licences; this might be incorrectly set, leading to an inefficient outcome. If there are too few national licences, then aggregation risks may remain (depending on the auction format chosen); if there are too many, regional bidders may be unfairly penalised and competition for national licences undermined.

54. Furthermore, depending on the auction format, national bidders may face impediments in switching between national lots and aggregations of regional lots, at the same time as regional bidders may not want to bid for national lots. Creating a somewhat arbitrary split of the available spectrum into national and regional lots might increase the scope for gaming and/or tacitly collusive outcomes, as switching impediments may prevent regional and national bidders being brought into effective competition with each other.

55. Conversely, offering all of the available spectrum as regional licences would allow for the award process to determine the split between national and sub-national footprints on the basis of demand by allowing bidders to recombine regional licences if they wished. However, while this suppresses the risk of regulatory failure from an administrative decision on the split between national and regional licences, an optimal split can only be guaranteed if bidders are able to express their demand effectively which requires addressing aggregation risks. Otherwise, bidders seeking to aggregate across regions may withhold their demand, which could lead to outcomes where the licences are too fragmented geographically.

Package bidding

56. Aggregation risks can be removed entirely through the use of a combinatorial award format, where participants

make bids for 'packages' of lots and they can only be awarded one of their packages in its entirety or otherwise nothing at all (we refer to this as 'package bidding'). Package bidding would suppress aggregation risks faced by bidders who need to bid for multiple regional lots to achieve their target footprint. As a result, it would allow bidders with different existing footprints and different ambitions to acquire spectrum to compete on a level playing field.

57. Through the use of auction formats allowing package bidding – which remove aggregation risks – there is no reason to regionalise only part of the available spectrum. With package bidding, it would be possible to offer all of the available spectrum on a regional basis, whilst still allowing bidders to aggregate lots. This would remove any need for ComReg to determine a split of the available spectrum between regional and national lots.

58. Package bidding does introduce complexity into the auction process, both in terms of specifying how bidders may bid for individual lots or aggregations, and in terms of calculating results and prices and explaining this process to bidders. The process can be simplified by reducing the number of geographical areas for sub-national licences. However, this will effectively introduce some limitations with regard to the flexibility offered to bidders to determine their footprints.

Predefined vs. flexible packages

59. As an alternative to supporting fully flexible package bidding, one could offer a combination of pre-defined packages alongside, and in competition with, the individual lots that form the package. When determining the highest bid on each lot, the auctioneer would consider bids for such pre-defined packages against combinations of bids for individual lots, and either accept a package bid or individual lot bids so that the total value of selected bids is maximised. Bidders who bid for a package would be guaranteed that they would not be assigned only part of the package; however, they would have no certainty about whether they might win any complementary lots they may have also bid for which are not included in the pre-defined package.

60. Predefined packages can be used with the SMRA format, as explained below. For instance, it would allow ComReg to offer national licences in competition with regional licences so that demand in the auction determines the eventual split between national and regional. However, this still requires ComReg to determine which are the 'key' aggregations that will form the pre-defined packages, which entails a risk of regulatory failure in the definition of those pre-packages. Unless all relevant packages are included, this approach is more limiting than adopting a format that supports fully flexible package bidding.

2.1.2 The need for switching across regions

61. Some bidders may only be interested in a single region, in which case they would not have a genuine reason for switching across regions. Similarly, bidders interested only in a national licence may simply pursue the same bandwidth in all regions, and thus not have a reason to switch across regions. It is also possible that some other bidders may remain flexible with regard to their geographical footprint and may be willing to progressively shrink this by dropping some of the regions once they reach a critical price.

62. It is unlikely that some bidders may want to switch across regions in response to relative prices. However, we cannot rule this possibility out. For example, a bidder seeking a combination of regions, but subject to an overall budget constraint, may wish to switch between regions in response to prices. Other overall constraints might also lead to switching, for instance a bidder wishing to deploy a network of a limited size and willing to switch across regions to maximise expected profits, or a regional bidder wishing to explore the option of expanding to neighbouring regions but without a clear preference for a specific region.

63. However, allowing for switching across regions increases the scope for gaming opportunities. For instance, a regional operator may have an interest in driving the prices of regions on which it does not want a licence simply to increase the overall cost of bidders aggregating across regions that may be competing for the bidder's target region. These gaming strategies are

not just theoretical possibilities and have been seen in some auctions. Gaming the auction can lead to unfair and inefficient outcomes and should be discouraged by the auction design.

2.1.3 Complexity and the number of regions

64. A large number of small regions could make an auction complex. However, there are a number of aspects to complexity we should distinguish:

- A greater number of regions leads to an exponential increase in the number of possible combinations of regions.[10] Regardless of whether the auction format uses package bidding or not, these various combinations may need to be evaluated and relevant combinations valued by bidders. This increases the amount of preparation that bidders may need to undertake, which might arguably disadvantage less sophisticated bidders.
- When using a combinatorial auction format, the computational demands on the auctioneer in calculating the winning bids and prices to be paid are in general related to the total number of possible packages, which increases exponentially with the number of regions.[11] In auctions with many regions, it may be necessary to restrict bids in some way (for example, by limiting the number of distinct packages a bidder may bid for) in order to limit these computational demands.
- If package bidding is not adopted, then with more regions it becomes increasingly difficult for bidders to assess their chances of obtaining their desired

[10] If there are *n* regions, then there are 2^n-1 possible combinations of regions.

[11] Without any constraints on the nature of bids that can be made (for instance, a limit on the total number of distinct packages that can be bid for, a requirement of a minimum number of lots or restricting possible bids through the use of a bidding language), the computational demands are proportional to the number of possible subsets of lots and to the number of bidders. With commodity computing hardware, the number of subsets of lots could reach billions or tens of billions before it is necessary to restrict bids in some manner to control computational complexity.

footprint. To the extent that there are complementarities across regions, this will expose them to aggregation risks. A greater number of smaller regions will results in larger aggregation risks.

- With many open auction formats (including both the SMRA and the CCA), a greater number of smaller regions is likely to give options for strategic bidding whenever switching across regions is allowed. For example, bidders might be able to soften competition in a target region by bidding on a region they do not want, as this might drive up the cost faced by competitors bidding across both regions and in turn limit the budget they have available for the target region.[12]
- A finer regional structure makes greater demands on the auctioneer in setting reserve prices and licence conditions. The risks of regulatory failure may be greater as a result.

2.1.4 Level of disaggregation

65. When offering usage rights on a regional level there is a trade-off between admitting reasonable demands for regional licenses and auction complexity. Using a large number of small regions may allow for a greater variety of outcomes in terms of winners' footprints. Defining small regions increases the flexibility within the process to determine footprints on the basis of demand, provided that any potential inefficiencies arising from aggregation risks are adequately mitigated or suppressed by the auction design.

[12] Suppose bidder A is only interested in region 1, while bidder B wishes to acquire regions 1 and 2. Further assume that bidder B has a budget constraint that limits the total amount it might be able to spend across both regions. Bidder A can start by bidding on region 2 to increase the overall cost faced by B, as this will reduce the residual budget that B may spend on region 1 (which would be the total budget minus the price B has to pay for a licence in region 2). Once the price in region 2 is sufficiently high, bidder A can switch to region 1. This may allow A to win at a lower price than if it had bid straightforwardly, as bidder B's residual budget for region 1 will be exhausted at a lower region 1 price.

66. However, increasing the number of regions inevitably increases the complexity of the auction process. Indeed, adopting a finer regional structure than necessary to accommodate reasonable uses will increase the scope for aggregation risks (including for bidders seeking a small coverage areas if regions are sufficiently small). Excessive complexity is undesirable on the grounds that it increases the need for bidders to prepare for the award, and in the extreme may discourage participation. Therefore, the aim should be to allow all operators to express their demands (including reasonable flexibility over footprints) without creating excessive complexity. To make the auction as simple as possible, one would need to identify the largest regions consistent with enabling demand from regional operators with sufficiently strong business cases to stand some chance of winning.

67. If there are complementarities between regions, i.e. if the value of a licence covering multiple regions is greater than the sum of values of each region on a standalone basis, operators seeking a footprint that extends beyond individual regions may be subject to aggregation risks unless this is adequately addressed by the auction design. Operators seeking a large footprint, especially national players, are likely to be in this situation regardless of the level of disaggregation. Adopting package bidding would suppress aggregation risks for these operators. Furthermore, bidders seeking a large footprint and with little flexibility to reduce it may only need to consider a few packages. Therefore, provided that aggregation risks are addressed, the regional structure should be able to accommodate the requirements of bidders seeking smaller footprints without handicapping bidders wanting larger footprints.

68. In an ideal situation, regions would be determined such that regional bidders are able to bid for the region that suits their needs. However, there is no clear way of catering for all possible uses. For instance, if we consider the potential demand from existing FWA users, there does not appear to be a way of partitioning a national licence into regions such that (i) the same regional partition can be applied to all channels; and (ii) all operators would be able to bid for a region that corresponds to their existing licence coverage. Even if this were possible, existing operators may wish to

expand their current coverage, or may be willing to reduce it. The problem becomes harder when trying to also facilitate demand from other operators who may be willing to participate in the process and might have rather different demands. Given the potential differences across potential users, there is no feasible regional structure that would satisfy every individual user.

69. Operators who wish to acquire a licence for non-overlapping local areas within a region could alternatively bid under a consortium, and then share the licence if they win. This would allow such regional bidders to compete against larger bidders for the region more effectively.

70. As another alternative, where consortiums do not form prior to the auction, operators seeking a licence for a small local area might be able to engage in long-term leasing or trading agreements with spectrum winners, provided that this is compatible with licence conditions and with the intended usage of the spectrum by the primary licensee. Some bidders may consider this option when making their bids for regions that may be larger than their target footprint.

71. Reducing the coverage area of regional licences can broadly be expected to reduce the need for regional operators to come together in order to bid under a consortium. However, the problem would remain that the licence areas might not align precisely with some bidders' requirements. In theory, this might be overcome by moving to small regional areas, but this might create very significant complexity due to the large number of possible combinations of regions. This approach will rapidly increase the likelihood that operators will need to acquire multiple licences, especially given that there does not appear to be an easy way to map existing local area licences across all channels into non-overlapping regions.

2.1.5 Urban vs. rural

72. A key factor when assessing the number and size of regions is whether the resulting regional scheme will allow different classes of bidder to bid for what they

want and compete fairly. Many of the small 3.6GHz operators provide services exclusively in rural areas. Conversely, national operators and mobile operators are likely to require additional bandwidth in high-traffic spots, typically located in urban areas. Given the existing and potential future uses of this spectrum, it may be useful to consider separating the main population centres from other regions.

2.2 Lot size

73. In order to award rights of use for the spectrum on a technologically neutral basis, one would ideally want to offer lots consisting of small frequency blocks that bidders can then aggregate into a bandwidth that meets their requirements. 5MHz blocks are widely adopted as a building block that is compatible with bandwidths suitable for a wide range of users. Under the working assumption that a total of 350MHz are available for award, this would translate into 70 frequency blocks of 5MHz each.

74. The number of lots in the auction also depends on the number of regions for which licences are made available, as all the available frequencies would be available in each of these regions. For instance, under a modest assumption of five regions, offering the spectrum in 5MHz lots would yield 350 distinct lots, while offering the spectrum in 5MHz lots in ten regions would yield 700 distinct lots. Many regions translates in a large number of potential footprints, which in turn translates into a very large number of potential packages, especially if bidders are flexible to acquire different bandwidth in different regions. However, clearly not all of these theoretically possible packages are likely to be

commercially relevant packages that a bidder would be prepared to win.[13]

75. One way of reducing the number of lots available in the award is to increase the lot size. However, this will necessarily reduce the flexibility to allow bidders to express their demand. For instance, some bidders who might want to acquire an additional 5MHz block to use it as a guard band.[14] Nevertheless, increasing the lot size may be reasonable as a measure to limit complexity if a fine regional structure is adopted, as for instance if ten or more regions are defined.

76. We note that ComReg is proposing that adjacent TDD licensees in the 3.6GHz band should apply a default frame structure for uplink/downlink time divisions that would apply in the absence of any other agreement between these licensees. In this case, there would be no need for guard blocks between adjacent licensees in the band.

2.3 Grouping of lots according to frequencies

77. When some frequency blocks are deemed to be very close substitutes, then a reasonable simplification is to offer these blocks as identical, frequency-generic lots in a first phase (the 'main phase'), in which the total bandwidth assigned to each bidder, and then determine the specific frequencies that will be assigned to each

[13] For example, a bidder might want only certain combinations of regions, such a geographically contiguous regions. A bidder might want a minimum or maximum amount of bandwidth and only certain bandwidths might be desirable (for example, a multiple of 20MHz if the bidder wants to deploy 20MHz carriers). A bidder might want similar amounts of spectrum in the various regions when it acquires spectrum. Constraints such as these can eliminate a large number of the theoretically possible packages.

[14] As discussed below, our understanding is that usage in this band would be coordinated in that usage of 5MHz blocks neighbouring other users is likely to be subject to a mask to prevent interference. However some operators may choose to buy an additional guard block if their intended usage does not fit within the mask.

winner of such lots in a second phase (the 'frequency assignment phase'). In the main phase, bidders can then simply indicate how many such lots they wish to bid for.

78. However, it is important to ensure that lots offered as identical, frequency-generic lots should indeed be close substitutes, as offering lots of different value as identical lots would expose bidders to uncertainty about the lot they may eventually win, and thus limit the extent to which they can express their preferences. When some lots are heterogeneous or deemed to have sufficiently different value, then these should be offered separately. This can be done by defining a number of 'lot categories' to group lots according to their value or other parameters.

79. This approach of grouping similar lots into categories (which was adopted for the MBSA) can greatly reduce the complexity of the bid submission process as compared with bidders selecting specific frequency blocks. In addition, the selection of the frequency assignment plan in the second phase can take into account other considerations. For instance, the potential assignment plans can be limited to those that ensure contiguous frequency assignments to winners. This is desirable from a spectrum management standpoint, as it avoids unnecessary fragmentation of the band.[15] It is also beneficial in terms of reducing the uncertainty faced by bidders when bidding in the main phase, as the value of the spectrum won can be expected to depend on whether it is assigned as a contiguous frequency block.

80. Offering closely substitutable lots in categories can also reduce the duration of a competitive auction if an open format is used. If one lot in a category increases price, then all will do so in the same round. Conversely, processes that require setting a separate price for each individual frequency block may require many rounds of applying a price increment to a small number of lots each round in order to increase the price of close substitute when there is only little excess demand –

[15] Avoiding fragmentation improves spectrum use efficiency and may help to manage potential interference with and from neighbouring users.

which will typically be the case when the auction is close to an end. Given the potentially large number of closely substitutable lots in the auction we would recommend using lot categories otherwise the auction could be very lengthy.

Lot categories

81. With regional licencing, lots in different regions need to be offered in separate categories. However, further categorisation might be needed if there are good grounds to believe different frequency blocks have different value. As ComReg currently has two options for regionalisation, for the discussion below we denote the number of regions as *R*.

82. We are not aware of any evidence suggesting that there might be a material difference in the value of spectrum across the frequency range within the band. However, the presence of state services splits the band into a smaller block at the lower frequency end of the band (where a user could achieve at most 25MHz of contiguous spectrum) and a larger one at the higher frequency end of the band (which would be the only option for winning more than 25MHz). Therefore, it is appropriate to further categorise the lots available in relation to whether they correspond to frequencies in the first block (below state services) or the second block (above state services). This sub-categorisation would be necessary if bidders are to be offered a guarantee that they will be assigned the bandwidth they win in each lot category as contiguous frequencies.

Spectrum below the block assigned to state services

83. There is a total of 25MHz below the block currently assigned to state services. In principle, it would be possible to offer this spectrum in 5MHz blocks. This would yield five blocks of similar value which could be offered in a single lot category for each region, yielding a total of *R* lot categories with five lots each (so a total of $5 \times R$ lots). These should be offered in separate categories to those for spectrum above state services.

84. However, it seems that an outcome where more than one operator winning within the frequency range below state services is both unlikely and probably an inefficient split of this frequency range.[16] Therefore, it may be reasonable to offer the whole range as a single 25MHz block. Under this approach, we would offer the spectrum as a single lot in each region, yielding a total of *R* lot categories with a single lot each (so a total of *R* lots), which would be distinct to those for spectrum above state services.

85. The disadvantage of offering the whole 25MHz as a single block is that it may somewhat limit switching under some auction formats. Specifically, assuming that switching between lots below and above state services is allowed on a per MHz basis, bidders seeking less than 25MHz above state services might be unable to switch to the lot below state services, even when bidding for this lot might reduce their overall cost for a licence. This can be partially mitigated under some auction formats, as discussed below.

Spectrum above the block assigned to state services

86. Licences for use of frequencies above those currently assigned to state services could be offered in 5MHz blocks. This would yield 65 blocks. We assume that all blocks within the frequency range are of equal or very similar value. In this case all blocks can be grouped into a single lot category in each region. This would yield a total of *R* categories with 65 lots each (so a total of *R*×65 lots).

87. In the event that there were many regions it might be desirable to increase the lot size to reduce the total number of lots. However, note that the total amount of spectrum above state services is not divisible by 10. Therefore, increasing the lot size to 10MHz might require creating a distinct lot category for the residual

[16] For example, if there were two winners of this 25MHz, then one must win no more than 10MHz. This suggests that the spectrum would be inefficiently fragmented.

5MHz. However, the number of lot combinations with 30 (10MHz) lots in one category and a separate category with one (5MHz) lot is exactly the same as with 65 (5MHz) lots in a single category, so no simplification is achieved.[17] To achieve a simplification, the lot size could be increased to 20MHz, as this would reduce the number of lot combinations available for bidders relative to the case where the spectrum is offered in 5MHz lots.

2.4 Implications for auction complexity

88. The degree of regionalisation has unavoidable implications for the complexity of the award process. As a general presumption, finer disaggregation will tend to increase aggregation risks for at least some bidders. Therefore, finer disaggregation will strengthen the case for adopting an auction format involving package bidding. Also, the gaming possibilities arising from switching across regions will also increase with the number and heterogeneity of regions.

89. As discussed above, the point at which further regionalisation ceases to be beneficial is difficult to determine, and would in any case depend on where regional boundaries are set. However, we can assess the number of alternative footprints that would be available to bidders for specific numbers of regions. This has a direct impact on the complexity of the auction process, both in terms of the number of different packages that a bidder might need to consider and value, and (if package bidding is used) also the computational demands for the auctioneer in terms of determining winning bids (and depending on the pricing rule adopted, prices).

90. In Table 1 below, we show the theoretical maximum number of different regional footprints that would be available under different numbers of regions.

[17] It would be possible to achieve a simplification if the single 5MHz lot were taken out of the main phase of the auction and its winner were determined in the assignment stage.

Table 1: Options for regional structure

Regions	Possible regional footprints
4	15
5	31
6	63
7	127
8	255
9	511
10	1,023
15	32,767
20	1,048,575

91. The theoretical maximum number of packages is a worst-case scenario, as many of these possible footprints are unlikely to be commercially rational. For instance, taking the case of nine regions (as in ComReg's Option 2), we can logically link:

- regions that are geographically adjacent (sharing a common border) with each other;
- urban regions with each other (allowing for the possibility that some bidders might wish to put together collections of urban centres without the corresponding connecting regions).

This gives rise to the 'logical' links shown in Figure 2. If we assume that bidders are only interested in packages

of regions that are all logically linked in this structure,[18] the number of relevant packages falls from 511 to 421.

Figure 2: Logical links under option 2

92. In a combinatorial auction, the computational complexity of solving for winners (and prices if applicable) is proportional to the number of possible packages, unless we impose a restriction on the number of bids considered for each bidder. Assuming that, as discussed above, spectrum below state services is offered in a single 25MHz block, and spectrum above state services is offered in 65 5MHz blocks, the number of *theoretically* possible packages rapidly increases:

- With four regions, the number of theoretically possible packages is about 304 million; this is still solvable with regular computing equipment;
- With five regions, the number of theoretically possible packages increases to about 40 billion, which is already challenging unless a simplification is made by restricting the number of packages that bidders can bid for;

[18] By this we mean that the sub-graph of the undirected graph shown in Figure 2 containing only those regions in the package has a single connected component.

- With six regions, the number of theoretically possible packages increases to about 5.3 trillion, which is largely impossible to solve without some restrictions on the bids that can be made.

Therefore, for any regional structure involving more than four regions, solving the auction will require a limitation on the number of distinct packages that a bidder can bid for.

93. We could reduce complexity by increasing the bandwidth of lots, but this only has a modest effect. For instance, if we used 20MHz lots and a residual 5MHz lot for the spectrum above state services, then it would be possible to solve the auction for the case with five regions without any restrictions on the number of packages bidders can bid for (as there would be about 1.5 billion theoretical possible packages). However, determining winners and prices with six or more regions would still remain challenging. Therefore, there is relatively little benefit in reducing the flexibility that bidders have in determining the bandwidth they wish to acquire in order to reduce complexity.

94. Given this, we expect that for any regional structure with five or more regions it will be necessary to impose some restrictions on the bids that can be made. For instance, on could restrict the number of distinct packages that bidders can bid for, which is a relatively common approach. If we restrict this to at most k distinct packages and there are n bidders, the worst-case computational complexity is proportional to k^n regardless of the number of theoretically possible packages. For example, if we set a limit the number of packages bidders can bid for to 1,000, then the computational complexity would be reasonable if there were no more than 10 bidders.[19] Alternative bidding restrictions might also be possible (e.g. requiring that bidders may not include less than a minimum number of lots in each category, or restricting the bandwidth

[19] With fewer bidders, it may be possible to increase the number of distinct packages that each bidder can bid for. However, clearly it is necessary to cater for a reasonable worst-case scenario with regard to the number of bidders.

differences across regions); however, as when increasing the bandwidth of lots, this may also have a modest effect in addressing the computational challenges when there are many regions.

95. Although restricting the number of packages each bidder can bid for could in theory allow for using many regions, we also need to consider the complexity for bidders in determining which packages to bid for. The greater the number of theoretically possible packages they can bid for relative to the maximum number of packages they are *allowed* to bid for, the more selective they will need to be. We would therefore recommend not exceeding ten regions in order to ensure that the award is manageable and all interested parties should be able to participate. When restricting the number of packages each bidder can bid for, it is also important to use an auction mechanism that provides some guidance to bidders in the selection of appropriate packages (e.g. a dynamic auction mechanism in which bidders can see the regions in which their bids conflict with other bidders' demands).

2.5 Summary of recommendations

96. We would recommend that if ComReg wishes to offer regional licences, then all of the available spectrum should be offered as regional licences, letting bidders aggregate regions into their desired footprint as they wish. However, in this case we recommend that aggregation risks be eliminated by use of a combinatorial auction format. This would provide a framework in which bidders seeking different footprints can bid on a level playing field, which is necessary for the auction mechanism to be able to identify an efficient assignment of lots.

97. Offering the available spectrum in 5MHz blocks provides greatest flexibility to different types of bidder to express their demand for bandwidth in a largely technology-neutral way. Therefore, we recommend this approach where possible:

- The frequency range above state services can be offered as 65 5MHz lots in each region to provide the greatest flexibility for the auction mechanism to

determine the bandwidth for each winner. Offering this frequency range in fewer lots of at least 10MHz could reduce the number of packages that bidders can bid for, but this has only a modest effect in reducing overall complexity, so is not recommended.

- It is unlikely that an optimal assignment of spectrum would involve more than one user in the 25MHz frequency range below the frequencies assigned to state services. Therefore, we recommend that this range be assigned as a single 25MHz lot in each region. This is a reasonable simplification that should not constrain bidders' flexibility.

98. Given the large amount of spectrum available, we recommend that it should be assigned in a two-phase process. In the first phase, close substitutes should be grouped into categories comprising frequency-generic, identical lots. For each region, all the 5MHz lots could be grouped into a single category with the 25MHz lot in a separate category. Bidders would bid for some number of generic lots in each category; the first phase would determine the number of generic lots won by each bidder in each category. The main phase would be followed by a second phase to assign specific frequencies, corresponding to the generic lots they have won in the main phase.

99. The number of possible footprints increases exponentially with the number of regions. As a consequence, and especially given the large number of lots in each region, the complexity of computing the outcome of a combinatorial auction could be severe unless mitigating steps are taken. When using a combinatorial auction format with more than four regions, it may be necessary to constrain the bids that can be made. A common and effective way of simplifying computational complexity is to limit the total number of distinct packages that each bidder can bid for.

100. However, number of packages that a bidder might be interested in could be greater than this limit. In this case, a bidder would need to select the packages it bids for. The difficulty of this task increases with the number of theoretically possible packages, and therefore with

the number of regions. For this reason, we would not recommend using more than ten regions. However, even in this case, selecting packages may be challenging for bidders if they do not have sufficient information about where their demand may conflict with that from other bidders. Therefore, with a limit in place on the total number of packages that a bidder can bid for, it may be appropriate to use a dynamic auction format that feeds back information to bidders about the demand they face in each region; this allows bidders to identify where they may need to offer flexibility to accommodate other winning bids by bidding on alternative packages.

3 Measures to safeguard competition

101. In any spectrum award, we need to consider the possibility that winning a sufficiently large share of the available spectrum could restrict downstream competition (i.e. competition in the supply of services derived from that spectrum). If the value of spectrum came in part from anticompetitive motives, letting the highest value users win out would neither create the greatest economic welfare nor be in the interests of consumers. In such circumstances it might be necessary to set spectrum caps or take other measures to constrain the assignment of spectrum and protect downstream competition.

102. The 3.6GHz band has a number of potential uses, including for additional capacity by mobile operators, for fixed wireless services and for high-bandwidth nomadic services. Therefore, there are a number of distinct downstream markets that could be served by licensees in this band.

103. It is implausible that downstream competition between mobile network operators could be significantly affected by spectrum acquired in this award. There is a relatively large amount of spectrum available in the 3.6GHz band compared with other recent (and future expected) awards. This should allow for a number of winners each able to obtain sufficiently large bandwidths to allow spectrum to be used in a technically efficient manner to provide additional capacity in high traffic areas. There are also a number of other alternative bands that can provide capacity for MNOs (such as 2.6GHz and 2.3GHz).

104. With regard to fixed wireless and nomadic services, the downstream competitive environment is difficult to anticipate, as services based on LTE have yet to emerge. At the margins, any such services may also be in competition with wireline and mobile services. Therefore, there is no basis for setting a tight spectrum cap that might restrict the ability to offer such services (especially high bandwidth, high quality services). Nevertheless, it may still be prudent to set a safeguard cap to prevent any single bidder foreclosing access to this spectrum, as we discuss in detail below.

105. Equally there is no case here for reserving spectrum. There are a variety of potential users for this spectrum and it is difficult to anticipate how the band might be shared between them. There is no obvious case for reserving the spectrum for any particular class of user and, indeed, to do so might well prove inefficient. Furthermore, no operators will enter the auction already holding 3.6GHz spectrum (or other capacity spectrum that might be deemed as a reasonably close substitute for this) and so spectrum reservations would not be meaningful in this context as no bidders could be sensibly identified as incumbents who should be prevented from bidding for reserved spectrum.

Safeguard cap

106. Despite there being no need for any specific measures to protect competition, it may nevertheless be prudent to set a safeguard cap to ensure that the available frequencies will be reasonably distributed across a sufficient number of bidders. Such a safeguard cap would only be aimed at preventing extreme asymmetric outcomes in which a single operator can win sufficient spectrum to deny any other bidder from winning a sufficient amount of this band to be able to offer a viable service.

107. When assessing the options for such a cap we may need to balance two objectives:

- On the one hand, we wish to ensure a minimum number of potential winners in each region, so that at least two or more operators in each region should be able to acquire a usable minimum amount of spectrum;
- On the other hand, we want to allow bidders to bid for as much bandwidth as they require to provide high-speed, high-quality services in the downstream market which may in turn be important to effective competition with other operators (possibly using other technologies).

Ensuring a minimum number of potential winners

108. First, we consider the level of spectrum cap that would be needed to prevent a single (or two) operators from acquiring all of the spectrum available, so that some spectrum would remain available for a second (or a third) operator. For these purposes, we need to take a view about how much remaining spectrum needs to be available to offer a viable service, offering sufficient speed and quality to a reasonably sized customer base. Whilst we cannot rule out the possibility that a bidder might make use of even a small amount of spectrum (say even a single 5MHz), for the purposes of assessing the level of a cap we suppose that there should be sufficient remaining spectrum to allow spectral efficient deployment using LTE by the additional operator. In practice this would require such an operator to obtain 20MHz (as this carrier size exhausts economies on a bits/MHz basis); as an alternative we consider the case of 40MHz remaining (which would allow for two carriers of 20MHz).[20]

109. If we want to ensure that a minimum number of operators would be able to acquire 20MHz each, then:

- ensuring that there could be at least *two* potential winners of at least 20MHz each would only require a (very loose) spectrum cap of 330MHz (under this cap, even if one winner exhausts the cap, 20MHz would remain available for a second winner); and
- ensuring that there could be at least *three* potential winners of at least 20MHz each would require a spectrum cap of 165MHz (under this cap, even if two winners exhaust the cap, 20MHz would remain available for a third winner).

[20] We note that a number of respondents to consultation 14/101 suggested that they would require 20 or 40MHz of spectrum. In line with this, Plum Report 3: Analysis of the potential spectrum requirements for NGA services, ComReg Document 15/75, suggests that using multiples of 20MHz blocks can be expected to maximise spectrum efficiency and ensure that there is sufficient capacity at each base station to support multiple simultaneous, high-speed connections. However, the proposed lot structure does not preclude an operator from seeking a lower bandwidth.

110. If we want to ensure that a minimum number of operators would be able to acquire 40MHz each[21], then:

- ensuring that there could be at least *two* potential winners of at least 40MHz each would only require a spectrum cap of 310MHz; and
- ensuring that there could be at least *three* potential winners of at least 40MHz each would require a spectrum cap of 155MHz.

111. Notice that if we guarantee spectrum would be available for a potential third winner, then any outcome in which there are only three winners with one winner acquiring little spectrum (close to the minimum) would involve relatively symmetric holdings between the other two winners. Conversely, if the cap only guarantees the possibility of a second winner, then highly asymmetric outcomes are possible (the most extreme one being that in which one winner obtains up to the cap and the second winner only the minimum guaranteed). Therefore, if the cap were only to guarantee the possibility of a second winner, then it may be appropriate to guarantee that the second winner should be able to acquire sufficient spectrum (even if not necessarily half of the band) to allow it to compete effectively against the other larger winner. At the same time, this would allow for intermediate outcomes in which a second and a third winner share the spectrum not taken by the first operator.

112. For instance, if the cap is set at 270MHz, there would be at least 80MHz available not won by the largest winner. It would be possible for a second winner to acquire all the leftover spectrum, or also that two winners share the leftover spectrum (for instance with an outcome in which each wins 40MHz).

[21] For simplicity, we do not take account here of the fact that the available 350MHz is split by state services and so this 40MHz might not be in one contiguous block. We consider this issue below.

Allowing bidders to express reasonable demand

113. In terms of allowing individual bidders to express reasonable demand, we need to consider what is a reasonable maximum demand. One FWALA operator argued that its future requirements to provide its envisaged service might require 80MHz in three sectors, which adds up to a requirement of 240MHz, and that 120MHz would be a "bare minimum".[22] Therefore, one would ideally want to accommodate such demand if possible. Although we might debate about the quantum of spectrum actually needed for a viable competitive service, we note that by comparison 120MHz could allow 40MHz per sector and 180MHz would allow 60MHz per sector.[23]

Level of a safeguard cap

114. If one were to guarantee the possibility of three winners with at least 40MHz, then the maximum bandwidth that any single bidder could demand would be 155MHz.[24] This would not allow a single bidder to win 180MHz or indeed 240MHz. However, it would allow a single operator to win 120MHz or slightly above.

115. In the event that it was important for spectrum to be deployed in 20MHz wide carriers for spectral efficiency (as for example with LTE) then we need to also take into account that the available spectrum is split by state services, with 25MHz below and 325MHz above. If we wished to guarantee that there were at least three winners each with at least 40MHz - either in a single block or two blocks each with at least 20MHz – then the

[22] See page 30-31 of Imagine's non-confidential consultation response.

[23] Applying Imagine's approach to its envisaged network deployments for other amounts of spectrum.

[24] If two winners each won 155MHz, then there would be 40MHz remaining. Again, for now we are ignoring that the 350MHz available is split into two contiguous blocks of 325MHz and 25MHz.

cap would need to be reduced to 150MHz, rather than 155MHz.

116. Trying to ensure the possibility of two winners with at least 40MHz would allow a single bidder to demand up to 310MHz. If a single winner were to win at the cap, this would only leave 40MHz for any other winners to share. However, there is no obvious rationale for such a loose cap. It could be reduced to 240MHz without apparently excluding any reasonable uses. A cap of 240MHz on the largest winner would leave available 110MHz for others, which could still accommodate one or two other operator with a reasonable bandwidth.

117. Alternatively, the cap could be set at 180MHz. This level would still be too high as to guarantee the possibility of three winners, but would ensure that a second winner could obtain up to 170MHz or that two additional winners might get 80MHz to 90MHz each.

118. In summary, trying to ensure the possibility of three winners each with a sufficient amount of spectrum to provide reasonable services (say two 20MHz contiguous blocks or better) would require a cap at 150MHz. This does cut somewhat into the higher demands suggested in the consultation (i.e. up to 240MHz), but still meets reasonable minimum requirements. If one were less concerned about ensuring three operators with sufficient spectrum, and focus instead on ensuring that there is the possibility of an operator obtaining sufficient spectrum to provide enhanced services, then a cap at 240MHz would be adequate.

4 Auction design

119. Provided we can assume that competition in downstream markets is reasonably effective, if the auction design leads to spectrum being allocated to those who value it most, this should in turn yield the greatest benefits for the economy as a whole.[25] Therefore, the award rules should be designed with the aim of encouraging value-reflecting bids and promoting outcomes that generate the highest aggregate value from the spectrum (measured in terms of the sum of winning bids).

120. Our working assumption is that the spectrum would be offered in lot categories of frequency-generic lots, as discussed in Section 2. In this section, we first discuss an appropriate mechanism for the main phase, which determines the number of lots assigned to each bidder in each category. Then we provide an indication of how the frequency assignment stage could work on the basis of a sealed bid process.

4.1 The main phase

121. There is a tension between certain aspects of auction design, especially under a regional licencing scheme:

- on the one hand, it is desirable to mitigate aggregation risks to allow bidders wishing to acquire complementary lots to bid according to valuations;
- on the other hand, mitigating aggregation risks will usually introduce complexity in the mechanics of the auction process, which might in turn discourage participation if complexity becomes excessive.

122. In this award, complementarities between lots are likely to arise between:

[25] Formally, this also assumes that there are no externalities involved with spectrum usage.

- lots in different regions, for bidders seeking a footprint that requires several regions; and
- lots within each category, as bidders are likely to require more than one lot in each category to achieve their desired bandwidth.

Complementarities between lots will lead to aggregation risks unless these are addressed by providing sufficient guarantees to bidders. There is good reason to expect these aggregation risks to be severe for at least some bidders, in that it is reasonable to expect that *some* bidders may be seeking national footprints and that most bidders are likely to have a minimum requirement for spectrum to be able to offer viable services that is in excess of a single 5MHz block.

123. Further complications can arise when bidders may be willing to switch across lots, as depending on the auction format bidders may be exposed to the risk of ending up winning a combination of lots that is not their preferred one given the final auction prices. We call these *substitution risks*. Substitution risks can arise when there are frictions in switching across substitutable lots, which can create a situation in which a bidder is prevented from switching to an alternative lot even if that would be its preferred option. Such frictions are typically a result of activity rules in multiple round auctions, which narrow the options available to a bidder as the auction progresses.

124. In particular, a common scenario in auctions where the spectrum is offered in small blocks is one in which a bidder might want to assemble an aggregation of lots, but has a number of choices how to do this. For example, a bidder might want a minimum bandwidth in a certain frequency range or region, but might be willing to switch to the same bandwidth in a different frequency range or region. In such cases aggregation risks and switching impediments can interact adversely if bidders are unable to shift their demand across different aggregations cleanly in one move.

125. Substitution risks can be addressed by offering bidders the option to bid for alternative packages and adopting a winner determination mechanism that maximises bidder surplus given the bids received and the price rule adopted. This means that a bidder can express its valuations for a number of alternatives and then rely on

the auction mechanism to select the most preferred outcome against those valuations. Both the Combinatorial Clock Auction (CCA) and the sealed-bid, combinatorial auction adopt this approach.

126. Given the scope for aggregation and substitution risks, we consider that (i) package bidding is an essential feature for this award; and (ii) bidders should be given an opportunity to bid for mutually exclusive alternatives. Given this, we start our discussion of auction designs with combinatorial auction formats.

127. The first format we consider is the Combinatorial Clock Auction (CCA). This format was adopted in Ireland for the MBSA award. The CCA provides a framework that suppresses aggregation and substitution risks. It also encourages bidders to express their willingness to pay and flexibility for alternative bandwidths, which allows a better assessment when determining the optimal assignment of lots given the bids received. The CCA can also be preferable to a sealed-bid process in that it features an open stage (a multi-round bidding process during which some information about demand is disclosed to bidders) that may progressively reduce the uncertainties faced by bidders, helping them in deciding which bids to submit. This final feature can be helpful when a fine lot structure is used, as the iterative multi-round process allows bidders to explore conflicts between the lots they are seeking and if necessary adjust their demand in highly contested areas. This process can help bidders to understand what packages of lots they might plausibly be able to win, which can help to promote an efficient outcome. (Conversely, in a sealed bid process bidders may fail to identify some options that might work around competitor's footprints, so that some bidders may lose out entirely as a result).

128. However, it is undeniable that the CCA has complex mechanics, which could possibly discourage some potential bidders. The CCA may also present some challenges for bidders operating under a tight budget constraint, or governance issues for those with valuations materially above expected competitive prices. Therefore, we explore possibilities for simplifying the process, and under which conditions it may be possible to do so without compromising efficiency.

129. First, we consider the possibility of using a sealed-bid, combinatorial auction for this award. This format has many of the desirable properties of the CCA, also allowing bidders to suppress aggregation and substitution risks. It bypasses the open stage of the CCA, jumping directly to the submission of a final set of mutually exclusive, package bids. The mechanics of the bidding process are greatly simplified, as there is no need for activity rules or feeding back information to bidders. The process is also much quicker, as it consists of a single round. However, a sealed-bid does not provide an opportunity to reduce the uncertainty faced by bidders by providing them with dynamic information about demand. As a result, those subject to tight budget constraints or more uncertain valuations will not have an opportunity to update their expectations of value on the basis of further information on the expected demand from competitors and prices.[26]

130. We would not recommend adopting a sealed-bid format if we are not confident that bidders are certain about their valuations and have budgets that reflect this, which would allow them to express their demand profile. Another important consideration for this award is that a sealed bid process does not allow bidders to investigate compatibility of their footprints through an iterative process. This is an important limitation when using regional licencing, especially if there is a restriction on the maximum number of packages that each bidder may bid for in order to limit computational complexity in solving for the auction outcome. Therefore, we would not recommend using a sealed bid auction in situations where there are a sufficient number of regions that the question of selecting what footprint to bid on becomes difficult for bidders.

[26] This is so-called common value uncertainty, where there are unknown common factors affecting the valuations of different bidders. Such uncertainty may exist alongside idiosyncratic factors affecting each bidder's valuations. Where there is common value uncertainty, bidders may want to update their own valuation in the light of information about the valuations of other bidders.

131. We also consider whether simpler open auction formats could be suitable under some simplifying assumptions. In particular, we consider a simple clock auction and a Simultaneous Multi-Round Ascending (SMRA) auction using generic lot categories. Both of these formats are vulnerable to gaming, especially if regional bidders are able to switch across regions and can exploit this to exhaust competitors' budgets. Therefore, we assess under what conditions it may be possible to impose restrictions to limit gaming possibilities.

132. The clock auction has the advantage that it supports package bidding, in that the auction will only end if all bidders can be assigned all the lots they bid for in the most recent round. However, it is still subject to substitution risks (as it does not allow bidders to bid for mutually exclusive alternatives) and is likely to end with lots going inefficiently unsold under some reasonable demand scenarios.

133. The SMRA auction does not support package bidding. Some SMRAs include provisions aimed at mitigating aggregation risks. However, these provisions have limited benefits and at the same time may increase the scope for gaming. Moreover, the SMRA would be impractically slow when using many identical lots. Therefore, using an SMRA would certainly require simplifications of the lot structure to reduce the number of identical lots available.

134. Gaming is a serious concern both for the clock auction and for the SMRA. In particular, these formats might be conducive to:

- strategic demand reduction[27] (which may lead to a suboptimal distribution of lots amongst bidders if

[27] When bidders seek multiple lots, they may benefit from strategically reducing their demand at prices that are lower than their valuation for additional lots. This happens when final prices increase as a result of there being excess demand (as for instance in a clock auction or an SMRA auction, where bids cannot decrease round-on-round and bidders pay the amount of their winning bids). In this situation, reducing demand early increases the chances that the auction will end with low prices, and therefore the expected surplus for all bidders.

bidders who place the highest value on additional lots reduce demand early);
- tacit collusion to share the spectrum at a low price (which as strategic demand reduction may lead to a suboptimal distribution of lots amongst bidders); and
- predatory bidding (when some bidders may try to increase the cost of specific competitors or push them out of the auction altogether, or threaten to behave in this manner).

135. As a consequence, these formats may only be appropriate if the information and actions available to bidders are restricted to limit gaming. However, this may only be reasonable under specific demand conditions. As a drawback, such restrictions may also reduce the benefits from having an open stage.

4.1.1 Combinatorial Clock Auction (CCA)

136. The CCA is a combinatorial auction format that allows bidders to submit bids for alternative, mutually exclusive packages. The final winner determination is done at the end of the process on the basis of all the bids received. Once the winning outcome has been calculated, bidders do not have an opportunity to revise their bids. However, the CCA features an open stage that allows bidders to assess the demand from competitors and potential end prices.

Basic structure

137. The CCA consists of a clock auction bidding process (the clock stage) followed by a final round in which bidders can submit a number of mutually exclusive, package bids (the supplementary bids round).

138. The clock stage evolves over a number of rounds. For each round, the auctioneer announces prices for each lot category. During the round, bidders specify the lots they would like to acquire at these prices. No information about other bidder's bids is provided to bidders while the round is in progress. At the end of the round, if the demand from all bidders can be accommodated with the lots available, then the clock rounds end. Otherwise, a

new round will be required, for which the price for lot categories with excess demand is increased. Bidding during the clock stage is subject to activity rules that prevent bidders from increasing their demand for lots for which (relative) prices increase, and will constrain the bids the bidder can make in the supplementary bids round.

139. In the supplementary bids round bidders can make their final offers for alternative, mutually exclusive packages. The bids that each bidder may submit in the supplementary bids round are subject to constraints arising from the bids it submitted during the clock stage. These constraints essentially require that the final set of bids submitted by the bidder must be consistent with the demand profile that can be inferred from the bids it submitted during the clock stage.

140. After the supplementary bids round, winners and prices are determined using a combinatorial approach, taking into account all bids submitted during the auction (including both the clock stage and the supplementary bids round). The winning bids will therefore be those that generate the highest possible value, subject to selecting at most one bid from each bidder and ensuring that all bidders can be assigned the lots specified in their winning bids given the lots available.

Pricing

141. The CCA adopts a pricing rule that requires winners to pay a price for their lots that is at least as high as the value that could be obtained from assigning these lots amongst the other bidders. However, subject to the condition above, the CCA will minimise the total sum of prices paid in the auction. This rule reduces the scope for a bidder to affect its own price by reducing its bid, and thus the incentives to bid below the level that reflects its maximum willingness to pay for each package. Encouraging bidders to reflect their maximum willingness is desirable, as this information allows the auction mechanism to make a better assessment of how to assign the lots amongst bidders.

Activity rules

142. The activity rules narrow the bidding possibilities available to a bidder on the basis of the bids it submits in some key earlier rounds. These key rounds are those in which the bidder reduces its 'total' demand,[28] measured by means of a weighted sum of the lots for which the bidder has bid in the round. The weights for each lot are referred to as 'eligibility points', which reflect an allowed rate of switching between different lot categories.[29]

143. When a bidder reduces its total demand, this creates a constraint on future bidding options. Specifically, suppose that the bidder reduces its total demand by switching to package *X* in round *n*. Any package *Y* involving a total demand that is no greater than the bidder's total demand in the previous round, but greater than the bidder's demand in round *n*, would be subject to a constraint. This constraint will limit the amount that the bidder can offer for *Y* in relation to the amount that the bidder offers for *X*. Specifically, the bidder's bid for *Y* cannot exceed its bid for *X* plus the difference in the price of these packages in round *n*. The rationale for this is that the bidder could have bid for *Y* when the price difference between *Y* and *X* was below this; however, by bidding on *X*, the bidder indicated that it was not willing to pay this difference to obtain *Y* instead of *X*.

144. These constraints limit the bidding options for the bidder both during the clock stage and the

[28] Some times it may be reasonable to prevent switching across different groups of lots. In this case, one would measure the total demand for each group separately. This approach was used for instance in the MBSA, where usage rights were offered in two distinct time slices and bidders were prevented from switching across these.

[29] For instance, suppose there are two lot categories, A and B. Lots in each of these categories are assigned one and two points respectively. The total demand of a bidder would be measured as the number of A lots the bidder bids for times the eligibility points for A lots, plus the number of B lots the bidder bids for times the eligibility points for B lots. Therefore, the bidder would be able to switch between two A lots and one B lot without changing its total demand.

supplementary bids round. During the clock stage, the bidder will only be able to bid for *X* if the price difference between *X* and *Y* does not increase, and provided that it updates its bid for *X* if necessary to ensure that its bids are consistent with the constraints. During the supplementary bids round, the bidder's final set of bids will also need to satisfy all these constraints, which may require increasing the bids for some packages that the bidder bid for during the clock stage.

145. For this award we propose using the relaxed activity rules adopted for the MBSA. This will impose a further, similar constraint on supplementary bids (the 'final price cap'), requiring that all bids submitted by the bidder must be consistent with its choice in the final clock round. The final price cap will limit the amount that the bidder can bid for any package *Z* other than that for which it bid in the final round (the 'final package') to its highest bid for its final package plus the price difference between *Z* and the final package. This allows bidders to calculate the maximum price it may need to pay to win its final package, which determines the maximum bid that the bidder would need to ensure it outbids its competitors for its final package.

Guarantees offered to bidders

146. The CCA suppresses aggregation risks by supporting package bidding, which provides a guarantee that a bidder will win a whole package it bid for or nothing at all. The CCA also suppresses substitution risks by allowing bidders to bid for alternative, mutually exclusive packages with a guarantee that the winner determination mechanism will select that which would provide the greatest surplus to the bidder (in terms of the difference between the bid submitted by the bidder and the price it would need to pay for each package). This property, in combination with the pricing rule, reduces incentives to reduce demand early in order to keep clock prices low, as the bidder should obtain at least the same surplus by bidding straightforwardly according to valuations (assuming that competitors' bids were unaffected by the bidder's bid during the clock rounds).

147. Bidding above valuation does not increase the chances of winning at a price below valuation. This is because the price for each winner cannot be less than the minimum it would have needed to bid to outbid its competitors. Therefore, a bidder who bids above its valuation will only increase its probability of winning relative to bidding at its valuation if winning would require the bidder to pay above its valuation – if the price to be paid were lower than or equal to its valuation, then the bidder would have also won by bidding at valuation. This is an important property that suppresses rational incentives to bid above valuation in an attempt to increase the probability of winning.

148. Finally, the CCA allows bidders to calculate the maximum price they may need to pay for their final package (especially when the relaxed activity rules, under which an upper bound for this can be obtained with a simple calculation). If such price is below a bidder's valuation, then the bidder would be able to calculate its 'guaranteed surplus' and adjust all its bids accordingly in order to reduce the absolute maximum bid it needs to submit to win its preferred package (and the amount of any potential deposit that may be necessary to back its bids).

Guarantees offered to the auctioneer

149. Provided that each bidder submits a set of bids that reflects its full demand profile, the CCA will assign lots efficiently to maximise value. As a consequence, lots will only go unsold when it would not have been possible to generate additional value from assigning them (on the basis of bids received).

Gaming opportunities and incentives

150. The CCA considers all bids submitted during the auction in the determination of winning bids and prices. Bids submitted in the clock rounds set constraints on the bids that a bidder can submit in the supplementary bids round. Bidding in a non-straightforward way with the aim steering the auction outcome entails a higher risk of not being able to express demand. For this reason, the

CCA provides good incentives for bidders to bid straightforwardly according to valuations.

151. Some commentators[30] have criticised the CCA on the grounds that it provides incentives for overbidding in order to impose higher prices on competitors, and that if bidders overbid too much they may end overpaying for the spectrum that they win. These concerns are unlikely to be material in practice. It is true that bidding incentives in a CCA are rather different to those in other open formats due to the fact that losing bids do not affect bidders' own prices, but may set competitors' prices. As such, the CCA may provides incentive to bid for packages that the bidder does not expect to win. However, if bidders got their assessment wrong, they could win with those bids, and therefore end up with an unwanted package or a price that exceeds valuation. This risk should have a desirable disciplinary effect and discourage such behaviour. The CCA provides a clear framework in which bidders can avoid overpaying for any package. Therefore, the critique of the CCA might be more related to the fact that prices can be higher than in other formats where there might be strong incentives for strategic demand reduction or that might be more susceptible to tacit collusion.

152. Indeed, in a CCA bidders do not have incentives to suppress their demand for additional lots. Losing bids for larger packages do not affect a bidder's price in the event that it wins a smaller package. As a result, the CCA is more effective in eliciting demand from bidders as they have good reason to compete for larger packages of lots up to valuation even if these bids prove ultimately unsuccessful.

153. The CCA destabilises tacit collusion by providing an opportunity for bidders to deviate from any tacit agreement in the supplementary bids round without the risk of retaliation by competitors. In a one-shot situation, deviating from any tacit agreement cannot

[30] See Levin J. and A. Skrzypaczy, September (2014) "Are Dynamic Vickrey Auctions Practical?: Properties of the Combinatorial Clock Auction" available at http://web.stanford.edu/~jdlevin/Papers/CCA.pdf

disadvantage bidders who deviate, especially if bidders cannot verify competitors' behaviour (e.g. if all bids are kept confidential), bidders have little incentives to stick to such an agreement. Furthermore, there may be benefits from deviating, for example by making supplementary bids for larger packages, as a bidder might then have some chance of winning one of these. As a consequence, while still possible, collusion in a CCA may be difficult to sustain.

154. Setting prices on the basis of the demand displaced by each winner can also lead to material price asymmetries when only some winners have unsatisfied demand for additional lots beyond what they have won. This could yield counterintuitive results when bidders are highly asymmetric in terms of the bids they have made. For instance, consider a simple scenario in which we have eight lots, a 'strong' bidder with flexible demand between four and eight lots, and a 'weak' bidder with demand for four lots. Suppose that the weak bidder manages to outbid the strong bidder on four lots, so that both bidders win four lots each. In this case, the weak bidder will need to pay the amount that the strong bidder offered for four additional lots; conversely, the strong bidder will only have to pay reserve, as the weak bidder did not express demand for more lots than it wins. Therefore, despite the fact that both bidders win the same package, the strong bidder would emerge from the auction with a better deal. This occurs because the lots assigned to the weak bidder were contested, while the lots assigned to the strong bidder were not. However, such outcomes may raise concern about the 'fairness' of the pricing rule, for instance on the basis that the demand for additional lots from weak bidders may be limited by their budget. Asymmetric spectrum caps may lead to similar results, as they limit the extent to which capped bidders can express demand for additional lots.[31]

[31] An analogous example to that above would be that in which a 'capped' bidder can only bid for four lots, while an 'uncapped' bidder can bid for all eight lots.

155. Other arguments made against the CCA relate to potential situations in which strong bidders with predictable demand might be at the mercy of weaker bidders that can inflict high prices to force strong operators to reduce demand. Arguably, this would require weaker bidders to have a high degree of certainty on the demand from strong bidders to know to what extent they could drive prices paid by stronger bidders without winning themselves. Therefore, these concerns are of little practical relevance in the context of this auction, in which there is a large supply of spectrum and demand from competitors might be highly uncertain. Moreover, under the informational assumptions necessary to support this argument, this would be a potential issue under most auction formats, so it is not a specific problem with a CCA.

Complications

156. Complications in the CCA arise when bidders may be unable to express their demand fully – including their preferences across different packages of lots - through their bids. This can happen for various reasons:

- Some bidders may be unable to obtain a budget that reflects their highest valuation for a combination of lots, and so may not be able to bid at value for all possible packages. In particular, this may mean that a bidders cannot express its valuation differential between a larger and a smaller package of lots, as bidding the smaller package at value would cause the bid for the larger package to exceed its budget if the true valuation differential was expressed. The bidder would have a choice between bidding less for the smaller package to bid the large package at its budget, if it thought this would likely win the large package, or alternatively if it was unlikely to win the large package at its budget, bid for the small package at

value, but then understate its valuation differential.[32]

- If there is a restriction on the maximum number of packages that bidders can bid for, as this may limit the extent to which a bidder can express its demand profile by means of alternative options, even if it had sufficient budget for all options. The bidder would need to select relevant packages that it thought it would have some chance of winning.

157. The CCA mitigates this problem by disclosing demand information during the clock stage that helps to assess what the bidder could realistically win. This information may allow bidders to calculate an upper bound on the price they may need to pay for the package they bid in the final clock round, especially under the relaxed activity rules adopted for the MBSA. On the basis of this information, the bidder is able to assess how much it could reduce its bids without risk of undermining its chances of winning. However, bidders operating under a tight budget constraint may still be unable to express their demand profile within their budget; such bidders may need to further adjust their bids to maximise their chances of winning on the basis of their expectations on what they might be able to win.

158. Even if bidders may be able to have access to sufficient budget, it is often challenging to get approval to submit a bid at a much higher level than the expected price for the package. This may create governance issues for some bidders. However, this problem is also mitigated by the relaxed activity rule adopted for the MBSA, which provides better information to calculate an upper bound on the price for the package a bidder bid for in the final clock round and thus may limit the extent to which the bidder needs to bid above likely end prices.

159. These complications could be magnified when using a regional structure if bidders were allowed to switch across lots to distort clearing prices without

[32] Budget constrained bidders in such a situation will generally need to form expectations about what they can realistically win within their budget in many auction formats.

consequences for the final bids they can submit. This could allow some bidders to distort relative prices at the end of the clock stage and create excess supply at those prices. This would limit the extent to which bidder can use the information from the clock stage when determining their final set of bids, as when the value of lots in excess supply in the final clock round is significant the maximum price that a bidder might possibly need to pay for some packages may be materially above final clock prices.[33] However, the relaxed activity rules adopted for the MBSA reduce the extent to which final prices might exceed the clock prices at the end of the clock stage, and also the scope for bidders to artificially create situations of excess supply in the final clock round without facing adverse constraints when submitting their final set of bids in the supplementary bids round.

Overall assessment

160. A CCA provides a good framework for bidders to be able to compete for diverse footprints and bandwidths, as:

- by supporting package bidding, the CCA provides a framework for bidders to bid without aggregation risks;
- at the same time, by using generic lot categories and providing an opportunity for bidders to submit mutually exclusive bids for alternative packages, the CCA provides a framework for bidders to bid without substitution risks; and
- finally, by selecting bids so that the difference between bid amounts and prices are jointly maximised it ensures that bidders who submit a set of bids that reflects their preferences should win with their preferred bid (as a consequence, the CCA has the advantage that it eliminates incentives for

[33] Such situations have occurred in some CCAs, as for instance the recent Canadian auctions or the 4G auction in the United Kingdom. Note that in the end the prices paid by bidders may be moderate or even below final clock prices, but bidders may face challenges when submitting their final bids in the supplementary bids round.

strategic demand reduction and promotes competition for additional lots).

Provided that bidders can reflect their valuations in their bids, the CCA is likely to perform well under any demand profile.

161. These properties make the CCA are a good choice for this auction, where complementarities between lots are to be expected. However, despite suppressing bidder aggregation and substitution risks, the CCA can present some challenges for bidders.

162. First, the activity rules and the process for determining winners and prices in the CCA are often perceived as complex. This could discourage some bidders, and possibly disadvantage those who fail to understand the rules if they then fail to understand the consequences of their bids. This issue may be mitigated by providing appropriate guidance and training to bidders; however, this may somewhat increase the work needed when preparing for the auction.

163. Second, the uncertainty about the final outcome may also raise concern for some bidders, especially they are unable to express their demand profile by means of a complete set of value-reflecting bids. This can occur when there are significant limitations on the bids that bidders can submit (as for instance a significant reduction on the total number of packages that each bidder can bid for) or if bidders' valuations are materially above their budget. Notwithstanding this, the CCA can assist bidders in identifying which packages they are likely to win within their budget, especially under the activity rules adopted for the MBSA. This allows bidders to focus on these packages and adjust bids to improve their chances of winning their preferred affordable package given their budget.

164. Table 2 provides a summary of key advantages and limitation of the CCA for this award.

Table 2: Key advantages and limitations of the CCA for the 3.6GHz award

Key advantages	Key limitations
• Bidders do not face any aggregation risks • There is no risk of overshoot or lots going inefficiently unsold due to lumpy demand • Provided that bidders submit a final set of bids that reflects their valuations, the CCA yields an efficient outcome without requiring any specific assumptions to be made about the structure of demand • Price differences across packages reflect complementarity between lots and opportunity costs, so both winners and losers should be happy if their bids reflect their valuations • Incentives to engage in strategic demand reduction are greatly reduced by not requiring a uniform price per lot, which allows bidders to compete for a large package without pushing the price they might have to pay to win smaller packages • With many regions the clock rounds can discover an outcome in which bidders have mutually compatible footprints, which can then inform the selection of packages to be subject to supplementary bids • Bidders need to focus on valuing packages prior to the auction and the gains from gaming behaviour are relatively modest	• Potential difference between valuations and likely prices may create governance issues for bidders seeking approval of bid ceilings • Opportunity cost pricing may lead to price asymmetries, in that smaller bidders may create little pricing pressure on larger bidders, but may have to pay dearly to out bid them (though this issue can be mitigated by setting reserve prices close to expected market prices and is unlikely to be relevant given the large amount of spectrum available here)

165. Below, we explore whether the process could be simplified for this award without compromising

efficiency. We start by looking at the sealed-bid, combinatorial auction, which simplifies the process by omitting the open stage of the CCA. We then consider a clock auction, which retains the open stage of a CCA whilst removing the supplementary bids round, and with it the uncertainty about the final outcome at the end of the open stage. Finally, we look into the SMRA auction, which is often proposed as an alternative by potential bidders who object to the CCA.

4.1.2 Sealed-bid, combinatorial auction

166. The sealed-bid, combinatorial auction calculates the winning outcome on the basis of bids received in a single round. As in the CCA, each bidder can bid for multiple alternative, mutually exclusive bids. However, the sealed-bid, combinatorial omits the open stage, and thus does not feedback information to bidders to assist them in assessing the demand from competitors and likely end prices. The sealed-bid, combinatorial maintains many of the desirable properties of the CCA – namely the elimination of bidder aggregation and substitution risks, and the fact that bidders who deviate from valuations face the risk of an undesirable outcome, which provides good incentives for straightforward bidding. However, it also retains some of its disadvantages, namely the perceived complexity of the mechanism used for determining winners and prices, the challenges faced by bidders operating under a budget constraint and governance issues for those bidders with valuations materially above likely prices.

167. Omitting the open stage relative to the CCA has the advantage that the process is greatly simplified, in terms of bidding mechanics, implementation and time required to complete the award process. In particular, a sealed-bid does not require activity rules, and thus avoids impediments to switching and the need to anticipate the consequence of bids in limiting subsequent bidding options. However, the absence of an open stage means that bidders must make their final set of bids without having and opportunity to mitigate their initial uncertainty about the final outcome.

168. This is a particular problem in this award. Due to the large amount of spectrum and regional structure, there

are many possible packages and it would likely to be necessary to limit the number of distinct packages that bidders can bid for to manage computational complexity. However, without the benefit of an open stage it may be difficult for a bidder to know which packages it should bid for because it would stand some chance of winning them. In a sealed bid, a bidder might fail to win anything because every one of its package bids conflicts with a winning bid of another bidder; however, small adjustments in these packages might have allowed one to have become a winning bid.

Basic structure

169. In a sealed-bid auction, bidders are given one single opportunity to submit their bids. Bidders specify the alternative packages they wish to bid for, and the amount for each of these bids. A bidder's bids are mutually exclusive, with at most one of these winning. As there is only one round there is no need for activity rules or feeding back of round-by-round auction progress information to bidders.

170. The winning bids are selected so that the total value of bids accepted is the greatest possible given the supply of lots. This optimisation problem is usually called 'winner determination'. The same process is used as for a CCA.

Pricing

171. The sealed-bid, combinatorial auction can be used with a first-price rule (bidders pay the full amount of their bid) or opportunity cost pricing identical to that used in the CCA.

172. An alternative is to use a first-price rule in which winners pay the amount of their winning bids. This may have some advantages when bidders are highly asymmetric and competition limited, in that it may encourage participation from weaker bidders if information about bidders is not disclosed. However, the first-price rule increases strategic complexity in that a bidder's bid determines its own price and expected surplus, and thus bidders have an incentive to reduce their bids to the

minimum they expect to be needed to stand a good chance of winning. As a consequence, the winning outcome depends on bidders' expectations about the strength of competition, which might turn out to be wrong and so lead to an inefficient assignment.

173. Conversely, under opportunity-cost pricing, bidders' decisions should be fairly simple provided that bidders have sufficient budget to bid in a way that reflects their actual demand. In particular, it is not necessary to second-guess what competition might be faced from other bidders, unlike a first-price auction. In such situations, an opportunity-cost pricing is likely to promote efficiency.

174. We believe that opportunity-based pricing is preferable for this award. This was the approach used in ComReg's 26GHz sealed-bid auction and same as the winner determination and pricing algorithm used in the MBSA.

Activity rules

175. None. The sealed-bid, combinatorial auction does not feature an open stage, and thus does not require activity rules.

Guarantees offered to bidders

176. The sealed-bid, combinatorial auction retains some of the key guarantees to bidders provided by the CCA, namely:

- it suppresses aggregation risks by supporting package bidding;
- it suppresses substitution risks by allowing bidders to bid for alternative, mutually exclusive packages with a guarantee that the winner determination mechanism will select that which would provide the greatest surplus to the bidder; and
- bidding above valuation does not increase the chances of winning at a price below valuation.

177. However, the sealed-bid, combinatorial auction does not offer any indication of the maximum price that a bidder may need to pay for a given price (which is provided in the CCA after the final clock round).

Guarantees offered to the auctioneer

178. As in the CCA, the sealed-bid, combinatorial auction guarantees an efficient assignment of lots provided that each bidder submits a set of bids that reflects its full demand profile. However, as discussed above it is possible that where there are restrictions on the number of packages that may be submitted (to manage computational complexity) bidders may fail to bid on packages that can mesh with other bidders packages and so fail to win; this might result in inefficient outcomes in complex auctions with many packages relative to the CCA.

Gaming opportunities and incentives

179. Gaming opportunities in a sealed-bid, second-price combinatorial auction are limited. Lack of information about competitors' behaviours is a strong destabilising factor against collusion. Furthermore, as there is just one round, there is no possibility of dynamic strategies for signalling or adapting to competitors' behaviour. As a result, the sealed-bid, combinatorial auction is robust against strategies such as strategic demand reduction, predatory bidding played out over rounds or tacit collusion.

180. As in the CCA, it is possible that some bidders may try to submit bids that are not reflective of their demand and are simply aimed at increasing competitors' prices. However, these strategies are highly risky when there is limited information about other bidders and their willingness to pay, as they may lead to the bidder winning a less preferred package, possibly at a price above valuation. As in the CCA, concerns about price driving are limited in this award given that demand for spectrum from different bidders is uncertain.

Complications

181. The sealed-bid, combinatorial auction can be subject to similar complications as the CCA, in terms of challenges faced by budget-constrained bidders, governance issues

and potential misunderstandings of the rules. Relative to the CCA, the problems faced by budget-constrained bidders and governance issues are significantly worse. This is because bidders are not given any information about the demand from competitors, and therefore must make final decisions on their bids on the basis of their prior expectations.

182. A sealed-bid, combinatorial auction may be particularly complicated for bidders context of auctioning regional licences, especially if it is necessary to restrict the total number of packages that each bidder can bid for, as would be the case if many regions are used. This is because if bidders cannot submit for all the packages they may possibly be interested in, then they need to make a selection of bids. However, unlike in a CCA, bidders would need to make this selection without the additional information provided by an open stage about the potential conflicts arising from competitors who only partly overlap with their target footprint. The CCA allows bidders to assess regional conflicts during the clock rounds, which may prompt bidders to offer flexibility to drop or contract demand in contended regions in their supplementary bids. Conversely, bidders in a sealed-bid auction will not benefit from this information, and might omit some key packages that could fit around the demand of their competitors. This leads to an increased risk of an inefficient assignment in the event that bidders fail to consider relevant packages.

Overall assessment

183. A clear advantage of using a sealed-bid process over the CCA is that it is easier to implement and conduct, and that the award can be concluded to a firm timetable. Using a single-round also simplifies the auction rules and mechanics greatly, and with this the work potentially required by bidders in preparing for the auction. Multi-round open auction formats aim to reveal information about relative demand and prices for different lot categories; however, this requires bidders to assess their preferred option at round prices and consider the implications that switching or reducing demand might have on their possibilities for bidding in subsequent rounds. This typically requires bidders to train and

actively and carefully consider their bids in a relatively tight round timeframe to avoid ending up in a situation in which they cannot submit the bids they would want. Conversely, bidding in sealed-bid process only requires bidders to carefully layout their bids once without bidding constraints that would apply to bid submission in a round of an open auction. Therefore, the sealed-bid auction entails a relatively lower risk of errors arising from a misunderstanding of the auction rules, as bidders will not need to worry about the implications of clock bids on their ability to submit their final set of bids.

184. The benefits from simplifying the bid submission would appear to increase with the number of lots and lot categories, for instance as a result of subdividing licences into smaller regions. Once bidders who wish to acquire licences in several regions have identified all their alternative target packages, filling in the bids for a sealed-bid process should be relatively easy. Even if there were many regions, it is possible to use a 'bidding language' to allow a parsimonious expression of demand for many packages. Conversely, bidding in a multi-round auction would require bidders to calculate and compare the cost of their alternative target packages each round at prevailing prices, which become more cumbersome as the number of regions increases.

185. However, such a simplification will not be achieved if bidders need to be restricted in relation to the total number of packages they can bid for, which is likely to be necessary when using many regions in order to control computational complexity in determining winners and prices. In this case, bidders could face a high degree of uncertainty when selecting the packages they bid for.

186. Obtaining information from demand in different regions may be key when a regional structure is used, especially if there were need to constrain the total number of package that each bidder can bid for. In this context, an open stage can assist bidders in identifying the packages for which they wish to bid. This is important if the number of packages a bidder can bid for is materially smaller than the total number of theoretically possible packages. Therefore, a sealed bid auction may not be appropriate if many regions are used, as for instance under ComReg's regional Option 2.

187. Another drawback of sealed-bid processes is that some bidders may feel uncomfortable about not being able to revise their bids in the event of an unfavourable outcome and might have regrets 'after the event'. This will especially affect bidders who have a tight budget and cannot bid up to their valuation, who may need to choose between alternative targets or may wish to revise their budget if they face stronger competition than they anticipated. More generally, this can affect all bidders if they are subject to common value uncertainty. Nevertheless, we should overstate these problems, as even in an open auction, the degree to which common value uncertainty is mitigated may be limited when there is a mix of bidders using different technologies and business plans that makes in difficult to draw inferences from others' bidding behaviour for one's own valuations.[34]

188. Table 3 provides a summary of key advantages and limitation of the sealed-bid, combinatorial auction, relative to the CCA, for this award.

[34] Bidders can mitigate common value uncertainty when they obtain information about the bids of competitors with comparable business cases (and thus subject to similar uncertainties). However, this would require participation from such bidders, and that detailed information about their bids be revealed. However, there is no guarantee that bidders with similar business plans will participate. Moreover revealing detailed information is usually avoided, as this could facilitate gaming and tacit coordination amongst bidders, increasing the scope for gaming, predatory or vexatious bidding and tacit collusive behaviour. Such behaviours could cause greater disruption and inefficiencies than common value uncertainty.

Table 3: Key advantages and limitations of the sealed-bid, combinatorial auction, relative to the CCA, for the 3.6GHz award

Key advantages relative to the CCA	Key limitations relative to the CCA
• Much simpler rules, as no activity rules are required • Faster process • Less preparation required • Not possibly for bidders to engage in dynamic strategies aimed at gaming the process • Incentives to submit price-driving bids further reduced by lack of information about competitors' demand	• Common value uncertainty is not addressed • No guidance about which packages might be more relevant to bid for because they might be potentially winning • Strategically complex for bidders facing tight budget constraints, as the process does not provide indication of likely prices and what packages bidders may win before bidders need to make their final bids • Governance issues for bidders with valuations materially above expected prices accentuated, as the process does not provide information for bidders to calculate the maximum price they may need to pay

189. A sealed-bid, combinatorial auction may be an appropriate simplification of the process provided that we are confident that:

- there is a small number of regions, so that any limits on the maximum number of packages a bidder can bid for do not materially constrain its ability to express its demand for all alternative packages;
- bidders have a budget that would allow them to bid at valuations;
- common value uncertainty is limited, or is unlikely to be materially reduced by the information that could be disclosed in the open stage of a CCA; and
- other bidder uncertainties are unlikely to affect their bids.

4.1.3 Clock auction

190. An alternative way of simplifying the auction process relative to when using a CCA is to retain the clock phase and drop the supplementary bids round instead. We would then have a simple clock auction. The clock auction provides an open stage, which mitigates uncertainty about final prices and the outcome as the auction progresses, and supports package bidding, as the auction will not close unless each bidder can be assigned the lots it bids for at prevailing round prices.

191. However, a clock auction does not provide bidders with an opportunity to bid for multiple alternative packages, and thus does not suppress substitution risks. In particular, switching between different categories of lots may be inhibited by the activity rules. The clock auction has also limitations arising from its pricing rule, which increases the risk of lots going inefficiently unsold. This format is also vulnerable to gaming, which might further compromise efficiency. It may be possible to somewhat mitigate these problems through restrictions on bidding behaviour. However, these may not be reasonable when we are uncertain about the potential requirements from different bidders.

Basic structure

192. In a clock auction, multiple items are grouped in categories of identical lots. The mechanics are simple: the auctioneer specifies a price per lot for each lot category, and bidders state the number of lots in each category they want at the prevailing price. If there is excess demand, then the auctioneer will raise the price for categories with excess demand and invite bidders to submit further bids. The auction ends when there is no excess demand, and all bidders who submitted a bid in the final round are awarded the lots they bid for at the final clock prices. Each bidder will then win the number of lots it bid for in the final clock round.

Pricing

193. Bidders pay the final clock round price for each lot they win.

Activity rules

194. The activity rules for the clock auction prevent a bidder from increasing its total demand (referred to as 'activity'). As in the CCA, total demand would be measured in eligibility points, which reflect an allowed rate of switching between different lot categories. However, the bidding restrictions arising from a reduction in total demand are stronger.

195. Bidders are assigned an 'eligibility level'. The eligibility level of a bidder determines its maximum allowable demand: in any round, the total activity of a bidder cannot exceed its eligibility. In the first round, each bidder starts with an initial level of eligibility, which may be determined with reference to its demand on application or its deposit guarantee. After the first round, the bidder's eligibility would be set to its activity in the previous round.

Guarantees offered to bidders

196. As the CCA, the clock auction suppresses aggregation risks by supporting package bidding, in the sense that the auction does not end unless all bidders can be assigned all the lots they bid for at prevailing prices. However, the clock auction will not suppress substitution risks, especially if there are material differences in the eligibility points assigned to different lot categories.

197. In the clock auction, winners pay the amounts of their winning bids; therefore pricing is much simpler than the CCA or the sealed-bid combinatorial auction. This eliminates uncertainty about prices and the challenges faced by budget-constraint bidders. It also eliminates governance issues for bidders in that they do not need to bid at a level that exceeds what they are likely to pay.

Guarantees offered to the auctioneer

198. The clock auction offers little guarantees to the auctioneer. In particular, there is no guarantee that lots will sell. Increasing price could cause demand to reduce below supply, leaving lots unsold.

199. The risk of unsold lots arises from the possibility that a bidder may withdraw its demand in big chunks, or even in full, from one round to another. This could lead to lots being inefficiently unsold. For instance, it is possible that multiple bidders may reduce their demand in the same round, and that it would have been possible to accommodate the demand of some of bidders who have reduced demand (in the previous round or earlier in the auction) given the final winning bids. However, lots may also go unsold as a result of a bidder decreasing its demand by multiple lots (for example, because it has a minimum requirement or because it withdraws from several regions at the same time); this may be unavoidable regardless of how small the round-on-round price increments are.

Gaming opportunities and incentives

200. Clock auctions provide an clear incentive for bidders to strategically reduce demand to prevent competition from increasing prices. In particular, the use of uniform prices (i.e. all lots in a category have a common price per lot) means that competing for additional lots will drive the price that a bidder would pay even if it were ultimately to win a smaller number of lots in that category.

201. For instance, a bidder may be willing to pay a higher price per lot for a large package than for a small package, as a result of complementarities. However, if the large package becomes increasingly expensive the bidder would prefer to bid on the smaller package. The clock auction does not allow a bidder to submit alternative bids to express this trade-off. Therefore, will need to choose what package they bid for on the basis of their expectation of likely prices. Indeed, the bidder may achieve a better outcome by reducing its demand early and acquiring the smaller package but at a lower

price per lot. This may create a strong incentive for bidder to settle for a smaller number of lots at a lower price rather than compete for a greater number of lots, possibly unsuccessfully.

202. These incentives for strategic demand reduction are accentuated when bidders have information about aggregate demand, which allows them to assess whether they could bring the auction to a close with a unilateral reduction in demand. This further increases the risk of unsold lots, as several bidders might reduce their demand to this end at the same time.

203. Another vulnerability of the clock auction arises from the fact that a bidder will only need to honour its final round bid. Bids submitted in a round are discarded if a new round is needed, which provides flexibility for bidders to switch around to manipulate excess demand prices when they are reasonably confident that the auction cannot end. This is a serious concern in the context of regional licences, as a bidder can be reasonably sure that the auction will not close if there is high excess demand for any single one of the lot categories. This could allow a bidder to bid for regions in which it does not intend to acquire a licence simply to raise the cost of competitors who are bidding across a number of regions, possibly motivated by a desire to reduce their residual budget for licences in regions in which the bidder does pursue a licence where competitors have budget constraints. Price-driving may also increase the risk of unsold lots, and may be used to sterilise some lots: a bidder might be able to drive prices beyond a certain level in a given category and then withdraw its demand so that lots remain unsold.

Complications

204. An important limitation of a clock auction with multiple categories is that switching could be highly restricted by the eligibility points used for each lot category. In the clock auction, a bidder that reduces its eligibility will be unable to submit any further bids that would involve an activity level greater than its new eligibility level. This can lead to substitution risks when lots have different eligibility levels. For instance, suppose the 25MHz block below state services is offered as a single lot in each

region (call this the A lot in that region), and the spectrum above state services is offered as 5MHz lots (call this B lots in that region). Further assume that the lots in a given region are assigned eligibility points in proportion to their bandwidth, so that A lots have five times the eligibility than B lots. A bidder who is bidding for 25MHz in a region can switch between the A lot and five B lots in response to price changes. However, if the bidder reduces its demand to 20MHz by bidding on four B lots, then the bidder will be unable to switch to the A lot, even if the price of the A lot were to be lower than the total price for four B lots. Similar situations can constrain switching across regions if lots in different regions are attributed different eligibility points. As a result, a bidder who reduces demand can be exposed to switching risks.

205. Note that switching impediments are not a problem in a CCA. In a CCA the eligibility points only determine when constraints for further bids arise; however, bidders are still able to bid for packages that require greater eligibility than that available to the bidder when they become relatively cheaper than in the round in which the bidder reduced eligibility. Conversely, eligibility reductions in a clock auction will simply remove bid options to bidders, as bidders are unable to bid for packages requiring greater eligibility than the bidder's level regardless of relative prices.

Overall assessment

206. The clock auction is much simpler than the CCA in terms of bidding mechanics and understanding the process for determining winners and prices. However, the clock auction involves a substantial risk of unsold lots when there are complementarities across lots. For instance, bidders aggregating across regions may exit several regions at the same time, leading to excess supply in some regions.

207. In addition, the clock auction creates strong incentives for strategic demand reduction. Setting prices close to expected clearing prices would reduce the potential benefits from strategic demand reduction. However, this may also increase the risk of choking off demand. Withholding information about aggregate demand

might also moderate the risk of strategic demand reduction by preventing bidders from assessing when they may be able to bring the auction to an end unilaterally. However, this will reduce the benefits from having an open stage.

208. A clock auction also has important vulnerabilities when bidders can switch across regions, as it allows regional bidders to drive the price up on regions that a bidder does not wish to acquire in an attempt to mitigate competition for their target regions. The scope for price-driving in non-target regions can be limited by restricting switching across regions. This would still allow bidders to start bidding on more regions than they target, but would prevent them from switching demand from target to non-target regions as the auction progresses in response to observed demand. However, this may be an unreasonable restriction unless we are confident that we can rule out the possibility that bidders might genuinely want to substitute different regions. If restrictions to switch across regions are considered we would suggest that these should be consulted upon to allow any bidder with a legitimate reason for switching across regions to raise its concerns.

209. Table 4 provides a summary of key advantages and limitations of the clock auction, relative to the CCA, for this award.

Table 4: Key advantages and limitations of the clock auction, relative to the CCA, for the 3.6GHz award

Key advantages relative to the CCA	**Key limitations relative to the CCA**
• Bidding mechanics are simple and the outcome is easy to verify • No uncertainty about the final outcome at the end of the clock stage • No governance issues relating to bidding above expected end prices • Uniform prices across all lots reduce the scope for complaints about 'fairness' of the outcome	• Bidders are exposed to substitution risks, especially there is material variance in the eligibility points for different categories • Ample opportunities for driving prices in non-target lot categories • High risk of inefficiently unsold lots • Strong incentives for strategic demand reduction

210. The clock auction is unlikely to be a good option for this award, especially if there is scope for substitutability between licences in different regions. Limiting the opportunities for gaming the auction would require:

- setting reserve prices close to expected final prices;
- potentially restricting switching across regions; and
- adopting a highly restrictive information policy.

211. However, these measures would reduce the benefits from adopting an open auction format, as they limit the information available to bidders, the extent to which bidders can adjust their strategy in light of this information, and the extent to which final prices are determined by actual (rather than expected) demand.

212. Overall, we do not recommend the use of a simple clock auction for this award.

4.1.4 SMRA with frequency-generic lots

213. The SMRA auction was the pioneer format for spectrum auctions. It is an efficient mechanism when bidders may acquire a single lot and must choose between (perfect or imperfect) substitutable lots in response to changes in prices. However, it has limitations when bidders seek multiple lots, as determining standing high bids on each lot independently of other lots exposes bidders to substitution and aggregation risks. In fact, the limitations of the SMRA in dealing with these risks has been the main motivation for developing and adopting combinatorial auctions for the award of spectrum licences when spectrum is offered in small lots that can be recombined by bidders.

214. Aggregation risks are likely to be important where bidders are seeking a footprint that requires several regions. A bidder trying to get a footprint covering several regions may be unable to secure all the component regions. In this case, the bidder may not wish to acquire only some of the regions, which might not even be geographically contiguous, or might prefer to switch to a different area altogether. The latter would require the bidder to wait until it is outbid on all regions, or alternatively withdraw any standing high bids if the auction rules allow for this. These problems are accentuated when regions are narrowly defined.

215. Aggregation risks may also arise because bidders want a certain minimum amount of spectrum, which requires them to win multiple lots in each region of interest. However, the SMRA provides no guarantee that this minimum will be achieved, as a bidder might eventually win fewer lots than its required minimum. This may be an issue where bidders are trying to win an appropriate bandwidth to allow efficient deployment of TDD-LTE (for example, ideally a multiple of 20MHz to deploy LTE carriers).

216. Addressing aggregation risks in an SMRA is not easy. There have been many attempts to introduce corrective measures, but none of them is entirely satisfactory. For example, provisions for withdrawals provide some flexibility for bidders wishing to switch across aggregations of lots, or who may want to acquire only a subset of the bids it has made. However, there typically need to be some restrictions to prevent strategic use of withdrawals for anticompetitive or vexatious motives. As a result, withdrawing bids usually involves some costs and thus will not suppress the risks faced by bidders. For example, if a bidder fails to acquire its minimum bandwidth, or wins an unworkable combination of regions, it cannot unwind this situation without cost by using a withdrawal.

217. Another approach to mitigating aggregation risks in a SMRA is to use a staged activity requirement. This allows a bidder to bid for only some of their target lots whilst maintaining eligibility to bid subsequently for a greater number of lots. The ability to maintain eligibility to make additional bids not currently being expressed is progressively removed throughout the auction. This allows bidders to assess their chances of winning some key lots before committing to bid on a wider set of lots.

218. Allowing bidders to assess demand in key regions before spreading out across of larger footprint can somewhat mitigate aggregation risks for some bidders. However, bidders may then adopt a number of strategies to avoid revealing their true demand by switching across regions, in which case initial rounds with a looser activity requirement could become a diversion that does not reveal useful information.

219. Furthermore, a staged activity requirement does not address aggregation risks arising from

complementarities over the total bandwidth a bidder wishes to acquire in a given regions, as all lots are identical and therefore it is not possible to assess demand for 'key' lots. A staged activity requirement may in fact be undesirable when bidders are likely to demand several identical lots, as it allows bidders to 'test' a demand reduction to achieve a tacitly collusive outcome without giving up their options to retaliate if competitors are not willing to accommodate.

220. Another relevant consideration for this award is that the SMRA can be unreasonably slow when there are many identical lots and little excess demand. Given the amount of spectrum available in this award, this is likely to be the case, at least towards the end of the auction. Therefore, adopting an SMRA might require reducing the total number of lots, possibly by increasing the bandwidth of lots for frequencies above state services. However, this removes flexibility for bidders to express their demand and for the mechanism to find an optimal distribution of bandwidth across bidders.

Basic structure

221. In an SMRA auction, multiple, specific lots are offered at the simultaneously and bidders select for which lots they wish to bid.[35] Bidding proceeds in rounds. All lots stay in play until the auction finishes.

222. At the end of each round, the auctioneer evaluates the bids received for each lot in turn, and selects a standing high bid on each lot. The standing high bids provide a provisional outcome. Where lots are over-subscribed, their price is increased for the following round. Bidders are then invited to submit further bids to change the provisional outcome.

223. Standing high bids remain valid and committing unless they are overbid in a subsequent round. This exposes

[35] Lots may be frequency-generic, which still reduces the risk of a fragmented outcome. However, unlike in the previous format, identical lots may have different prices, and bidders must select a specific lot rather than express a demand for a type of lot.

standing high bidders seeking multiple lots to aggregation and substitution risks:

- as standing high bids for different lots are established independently, bidders who bid on several lots may become standing high bidder on only some of the lots for which it bid;
- standing high bidders may be outbid on only some lots, so there is no guarantee that they will be able to retain a combination of lots;
- bidders who hold standing high bids on some lots cannot easily switch to non-overlapping aggregations, as they may be 'stuck' with their standing high bids.

224. Some SMRA auctions include provisions that allow bidders to withdraw standing high bids, typically subject to some restrictions (e.g. under specific circumstances or a limited number of times) and/or costs (e.g. penalties in the event that such lots remain unsold or eventually sell at a price below the withdrawn bid amount).

225. The auction ends when there is no more bidding activity, so that the provisional outcome cannot be displaced. At the end of the auction, the standing high bid on each lot becomes the winning bid on the corresponding lot.

Pricing

226. Bidders are required to pay the amount of their winning bids.

Activity rules

227. The activity rules if using a SMRA auction are based on the same concept of eligibility and activity as those for the clock auction. However, the activity rules in an SMRA can be extended to allow bidders to use waivers and withdrawals in order to help them to manage aggregation and substitution risks:

- A bidder who uses a waiver in a given round will be exempt from losing activity in that round. This allows bidders to gather demand information or wait before making key decisions. Waivers can also help manage substitution risks by allowing bidders

who wish to switch to a different combination of lots but are stuck with some standing high bids to wait to see if they are outbid on their standing high bids, so that they can switch to a new aggregation at once. Typically, bidders are allowed to submit a limited number of waivers throughout the auction, but not in the first round.

- Allowing bidders to withdraw standing high bids is also aimed at mitigating risks faced by bidders. A bidder stuck with standing high bids can withdraw them in order to switch to a different aggregation of lots. However, withdrawals are a double-edged blade, as they may also facilitate gaming by allowing bidders to withdraw strategic bids on lots they do not wish to acquire. Allowing withdrawals in only limited cases and subject to penalties will help avoiding highly undesirable outcomes (as bidders may be willing to incur the cost of withdrawal to avoid such outcomes); however, restrictions and penalties should be sufficiently harsh as to discourage bidders from strategically bidding on lots they do not wish to acquire.

228. As in the clock auction, the activity rules in the SMRA would prevent a bidder from increasing its activity. However, unlike in the CCA and the clock auction, a bidder's activity needs to take into account standing high bids, withdrawals and waivers. As in the other auction formats discussed above:

- total demand would be measured in eligibility points;
- bidders have an eligibility level for each round, which determines the bidder's maximum activity in the round (the total activity of a bidder cannot exceed its eligibility); and
- bidders' eligibility levels are adjusted downwards as the auction progresses if they decrease their activity.

However, in the SMRA the activity of a bidder is calculated as:

- the sum of the eligibility points of lots on which the bidder holds the standing high bid at the start of the round and which the bidder does not withdraw or raise in the round; plus

- the eligibility point of lot for which the bidder submits a bid in the round.

229. As in the previous formats, each bidder starts with an initial level of eligibility (often determined with reference to its demand on application or its deposit guarantee). After the first round, the bidder's eligibility would be set to its activity in the most recent round in which the bidder did not submit a waiver.

230. One possibility in the SMRA is to adopt a 'staged activity requirement'. The activity requirement establishes the threshold that triggers an eligibility adjustment, and the impact of any such adjustment. The activity requirement is expressed as a percentage between 0 and 100, and is typically increased during the auction in a number of steps, ending at or close to 100%. An activity requirement of X% means that a bidder's eligibility will only be adjusted downwards if its activity falls below X% of its eligibility; in this case, the adjusted eligibility level will be set to the bidder's activity level divided by X%. The conditions for the auction to end would then typically require that the highest activity requirement level had been reached, so that all bidders had an opportunity to express their maximum demand.

231. As discussed above, the motivation for a variable activity requirement is to allow bidders to first explore demand conditions for some key lots that are likely to be highly competed for, before having to bid for other, complementary lots for which they might be little competition. This allows bidders to avoid becoming a standing high bidder on weakly competed lots before they are reasonably confident that they may win more strongly competed key lots.

232. However, unless it were impossible to maintain the eligibility points required to bid for key lots by bidding on weakly competed lots, the staged activity requirement may also provides opportunities for bidders to withhold their demand for key lots or bid strategically for non-target lots in the early stages of the auction. This may mean that bids are not especially meaningful until the activity requirement is increased (possibly until it reaches 100%), rather defeating the usefulness of the staged activity requirement. In this case, the staged activity requirement will have limited benefits, and

simply increase the risk that some bidders might game the auction.

233. With a large number of small lots in each region, bidders are likely to be able to maintain eligibility needed to bid for key regions by bidding on a large number of lots in non-key regions. Therefore, a staged activity requirement could easily be exploited. On the other hand, it is not clear that ComReg would be able to identify key regions, or that it might be reasonable to assign to these lots a much larger number of eligibility points than to non-key lots, as doing so might prevent legitimate switching across regions. Therefore, we would not recommend using a staged activity requirement for this award.

Guarantees offered to bidders

234. The SMRA exposes bidders seeking multiple lots to aggregation and substitution risks.

235. In an SMRA, bidders have full visibility of the price they will have to pay in the event that their bid is selected as a winning bid. This eliminates uncertainty about prices and the challenges faced by budget-constrained bidders and governance issues for bidders whose valuations might be materially above likely end prices. However, bidders seeking multiple lots and holding some standing high bids cannot be assured of the price they may have to pay for complementary lots. Therefore, bidders may need to make their decisions on the basis of their expectations on final auction prices.

Guarantees offered to the auctioneer

236. The SMRA offers the guarantee that provided any bids are received for a lot, then the lot will sell unless the standing high bid on the lot is withdrawn (which may be subject to a financial penalty).

237. However, once there are complementarities across lots, the SMRA provides no guarantee that the lots will be assigned to bidders who value them, or at a price that is profitable for the bidder. Indeed, any lower risk of unsold lots relative to a clock auction or a CCA would

result from forcing bidders to take up any lots they bid for even if they would rather not buying those lots (for instance if they fail to also win complementary lots).

238. The SMRA also provides incentives for bidders to withhold their demand in order to bring the auction to an end at low prices, so the auctioneer has no guarantee that it will be able to assign the lots to those bidders who value them most, as it may not have the necessary information to assess this.

Gaming opportunities

239. The SMRA provides a wide range of gaming opportunities, especially when bidders can acquire multiple lots across regions. These include, for example, price-driving in non-target regions, hiding demand in the early stages of the auction, strategic demand reduction, predatory bidding or signalling in order to suggest a tacitly collusive outcome.

240. Much of the opportunity for gaming in an SMRA with regional lots arises from the ability of smaller bidders to switch between regions combined with the fact that bidders seeking large footprints may face aggregation risks across regions. This structure may create incentives for bidders seeking smaller footprints to bid for regions they do not ultimately want in order to create 'holes' in the footprint of larger bidders so that they lose synergies across regions, or to drive prices and exhaust the budget they have available for other regions. Also, various forms of predatory bidding are possible that can support tacitly collusive outcomes ("if you bid on my regions, I'll bid on yours").

241. Even without switching across regions, the SMRA provides incentives for strategic demand reduction. This is a natural consequence of the property that prices may only increase as the auction progresses, and therefore bidders may benefit be able to avoid further price increments by settling for a small number of lots early on. The incentives to do so are greater when reserve prices are substantially lower than expected competitive prices, as this increases the gains from avoiding competition.

242. For similar reasons, bidders can benefit from accommodating competitors or achieving a tacitly collusive outcome in which they share the lots available. The possibilities for bidders to indicate potential sharing outcomes and their intentions to competitors are greater in an SMRA than in a clock auction, as bidders may be able to send signals by bidding on specific combinations of lots or creating price differences between lots. These strategies are not simply a theoretical possibility, but have be seen in practice.(for in example in some US SMRAs with regional structures).

243. Adopting a restricted information policy can somewhat mitigate the risk of signalling and strategic demand reduction. For instance, bidders could only informed of the standing high bids they hold and the current price for each lot. However, bidders will still have an incentive to unilaterally withhold their demand to dampen competition in the auction. Furthermore, bidders in an SMRA may still be able to infer quite a lot about competitor's behaviour, especially if they rely on some assumptions about their competitors. This introduces the risk that some bidders could base their strategies on guessed behaviour of competitors, which might in fact prove wrong.

Complications

244. As in the clock auction (but unlike in the CCA), bidders who reduce their eligibility will be unable to submit any further bids that would involve an activity level greater than its current eligibility level. Therefore, as in the clock auction, attributing different eligibility points to different lots can create switching frictions by making switching between packages irreversible. In the SMRA, this will be further complicated by standing high bids, which may further complicate switching back and forth between substitutable packages.

245. Another complication arises when there are many lots, in that the price for each lot will only increase when a new bid on the lot is received. When there is only little excess demand, this means that many rounds may be needed before the price of all identical lots increase to a new level. This makes the SMRA unreasonably slow

when there are many lots available, as can be seen from recent awards that adopted the SMRA auction format.

Overall assessment

246. The SMRA auction was the most prevalent auction format in early spectrum awards and it is still used at present. In fact, the SMRA can be adequate for simple awards in which only a few similar lots are offered (i.e. lots are substitutes) and in which bidders can acquire at most one lot (i.e. there are no aggregation risks or switching impediments). However, it has important deficiencies and limitations for awards with many lots, especially if bidders have flexibility with respect to the number of lots they acquire and are subject to aggregation risks. Such limitations may not be relevant under very specific conditions of demand, but these are unlikely to apply to the current award. In particular, the SMRA would be likely to create unnecessary aggregation and substitution risks for bidders, which create impediments to eliciting demand information in the form of value-reflecting bids.

247. The SMRA is often proposed by some potential bidders, on the grounds that its simplicity encourages participation and reduces complexity. However, arguments in favour of the SMRA are highly dependent on market conditions. It is a general property that the SMRA reduces incentives to compete for additional lots when bidders can acquire multiple lots. This may lead to weaker competition and price reductions for bidders, but at the expense of increasing the risk of an inefficient outcome.

248. Concerns about tacit collusion in scenarios of limited competition can be mitigated by setting reserve prices as close as possible to the expected market value in a competitive auction and limiting transparency. Such reserve prices may also reduce the incentives to engage in gaming more generally. However, setting prices close to expected auction prices entails a greater risk of regulatory failure due to creating inefficiently unsold lots. In practice, uncertainty about the likely competitive price limits the degree to which reserve prices can be used in this way.

249. For this award, concerns about aggregation and substitution risks are of particular relevance. Offering the spectrum in small frequency blocks means that bidders will typically need to bid for several blocks without guarantee that they will win the bandwidth they require to make good use of the spectrum. Aggregation risks relating to bandwidth could be mitigated by offering the spectrum in larger blocks. However, this would reduce the flexibility of the process in determining the number of users and their share of spectrum on the basis of demand. Aggregation risks may also arise due to complementarities across regions. Again, aggregation risks could be mitigated by offering a smaller number of larger the regions. However, this would also reduce flexibility and would disadvantage regional bidders.

250. Having a large number of identical lots (as would arise here within a region) also has practical implications, in that increasing the price for all identical lots in an the SMRA when there is little excess demand can require many rounds. In practice, using an SMRA may require increasing the size of lots for frequencies above state services, as otherwise the auction may take an unreasonable time to conclude. This contrasts with the other formats, in which round prices for all identical lots within a category are increased at once. Therefore, a clock-based multi-round processes in which the auctioneer announces a price for a type of lot and bidders specify the number of lots they would wish to acquire is more able to cope with large number of identical lots.

251. Bidding straightforward according to valuations is often an obviously suboptimal strategy for bidders in an SMRA. Typically, bidders will benefit from adjusting their demand on the basis of their expectations of end prices in order to mitigate the risks they face. However, this will increase the risk of an inefficient outcome if bidders' expectations are wrong. Moreover, this can intensify asymmetries between bidders where some bidders may have better information than others.

252. Table 5 provides a summary of key advantages and limitation of the SMRA auction, relative to the CCA, for this award.

Table 5: Key advantages and limitations of the SMRA auction, relative to the CCA, for the 3.6GHz award

Key advantages relative to the CCA	Key limitations relative to the CCA
• There is a low risk of unsold lots, as a provisional winner can be assigned as soon as any bids are received on a lot (although such lots might not be efficiently assigned) • The bidding mechanics are simple and the outcome is easy to verify	• Bidders seeking multiple lots, either to achieve greater bandwidth or a wider footprint, face aggregation risks • Strategic complexity is much greater if bidders have complementarities across regions • Bidder seeking multiple lots are subject to substitution risks – bidders may not be able to switch aggregations if they are 'stuck' with standing high bids on some lots (or doing so may involve costs if there are penalties for withdrawing bids) • Large differences between the eligibility points for different categories will further increase substitution risks, as bidders may not have sufficient eligibility to switch to a relatively cheaper options once they have reduced their demand • There are significant incentives for strategic demand reduction and tacit collusion • May be very slow given that the are many lots available, leading to a very long and costly auction process • In practice the SMRA may require reducing the number of lots available by increasing the bandwidth of lots for frequencies above state services, which reduces flexibility for bidders to express their demand and for finding an optimal distribution of bandwidth amongst bidders

253. Given the likely strong complementarities between lots for at least some bidders, an SMRA auction seems inappropriate for the current award. Using an SMRA might also require adopting strong measures to reduce the scope for gaming, including a highly restricted information policy, possibly banning switching across regions, and high reserve prices to mitigate incentives for gaming. These measures require administrative decisions based on assumptions on the nature and structure of demand; as such, adopting an SMRA would entail a greater risk of regulatory failure in making these decisions.

4.1.5 Recommended auction format for the main phase

254. Given the characteristics for the award, we recommend adopting a CCA. A sealed-bid, combinatorial auction might be a reasonable simplification only if we are confident that bidders would be able to determine which packages are relevant for them to bid for in a situation in which there may be a great number of potential packages. This is unlikely to be the case, especially if many regions are used and it is necessary to restrict the maximum number of packages that each bidder can bid for.

255. Both the clock auction and the SMRA auction may involve significant risks for bidders and are particularly vulnerable to gaming when a regional structure is used. These increase the risk of an inefficient assignment. Therefore, we do not recommend using these latter formats for the current award.

5 Assignment of frequencies

256. The main phase of the auction would determine how many lots each bidder won in each lot category. In the case of categories containing multiple lots with our proposed lot structure, the 65 lots corresponding to the frequencies above state services for each of the regions – the actual frequency assigned would be determined in a follow-up phase.

257. The frequencies above state services form a single contiguous frequency block. As a result, it is always feasible to assign a contiguous frequency range to each winner in each region. Therefore, as a starting point, we recommend restricting the set of possible assignment plans to those that meet this condition.

258. A second objective might be to try to assign the same frequency range to winners of licences in several regions. This may be difficult (and in some instances might be impossible) if some winners win different bandwidth in different regions. Nevertheless, it is possible to guarantee that all winners who win the same bandwidth in *every* region are assigned the same frequency range in all regions (for example, this can be done by simply placing all these bidders next to each other in a single block, possibly at one end of the band).

259. In more complex cases, we can seek assignments that minimise some measure of 'mismatch' in how different frequency assignments are across regions for bidders. There are many potential ways to do this, but it is reasonable that priority is given to regions that are geographically adjacent.

260. For example, given a particular frequency assignment, mismatch could be measured in the following way:

- Any bidder receiving the same frequencies in all regions where it won lots would have zero mismatch;
- Otherwise, take a particular bidder and group the regions in which that bidder has won lots into connected components (i.e. groups of regions that are connected to one another by a common border);

- Take one connected component for a bidder and determine the common frequencies *CF* present in all regions (in MHz) under this frequency assignment. Determine also smallest amount of bandwidth *MB* (in MHz) won in any of these regions in the main stage. It always the case that *CF* is no more than *MB*. Define the mismatch for that component as the difference *MB – CF* multiplied by the population of the regions in that component[36];
- Sum across bidders and components to obtain an overall measure of mismatch.

261. This measure of mismatch prioritises bidders receiving the same 'core' frequencies across all contiguous regions. For example, suppose that regions *A*, *B* and *C* shared borders so formed a component for a bidder. The bidder won 20MHz in *A* and 30MHz in *B* and *C*. If the frequencies assigned in region *A* are also assigned to that bidder in regions *B* and *C*, mismatch is zero. Notice that the frequencies associated with the additional 10MHz in *B* and *C* might be different, yet mismatch is still zero. However, if the bidder were assigned entirely differently frequencies in region *B* and region *A*, then mismatch would be 10 times the population of *A*, *B* and *C*. If the bidder had also won lots in some region *D* that did not share a border with any other region won by that bidder, region *D* would not be relevant to determining mismatch.

262. To minimise fragmentation of the band we would recommend that:

- if there are any plans in which it is possible to assign the same frequencies to all winners in all regions in which they have won spectrum, then any other assignment plans are discarded;
- otherwise, only the plans in which minimise mismatch as defined above are considered.

263. Once possible assignment plans have been narrowed down by applying the conditions above, a one-shot

[36] Other more complex weightings are possible, such as taking into account the degree of interconnectedness of regions. Final clock prices could also be used as an indicator of the relative importance of different regions.

bidding process can be used to determine which of these assignment plans will win out. This can be done by inviting bidders to express their preferences, in the form of bids for alternative assignments they could win. Each alternative option would specify the frequencies they would receive in each region where they won lots, amongst those options available after applying the conditions above. The winning outcome would maximise the total value of winning bids. Prices associated with the winning bids can then be determined on an opportunity cost basis (what was called additional prices in the MBSA award).[37]

264. Bidding for assignment options is not subject to material risks and uncertainties that might impede bidders from expressing their demand. Therefore, a sealed-bid auction, which was the approach adopted for the MBSA, would work well. Bidders would be able to specify their value for each of their alternative options, and then the auction mechanism would select the assignment plan that yields the greatest value in terms of accommodating bids from different bidders. Note that winners from the main phase are guaranteed the lots they have won, and therefore bidders opting for not submitting a bid would still be assigned the bandwidth they have won.

[37] To calculation the opportunity cost, we would assume that a bidder has submitted no preference for any outcome, i.e. zero bids for all possible assignments.