Award of available spectrum: 10 GHz, 28 GHz, 32 GHz and 40 GHz: Spectrum packaging and auction design

Public discussion document

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Contents

Section 1

Executive summary

1.1 Ofcom published on 29 June a consultation document setting out proposals to hold an auction in 2007 for the award of wireless telegraphy licences in the 10 GHz, 28 GHz and 32 GHz spectrum bands. It also proposed to defer the award of licences in the 40 GHz band.

1.2 The key elements of the proposed spectrum packaging and award process were:

Twelve licences would be offered. Most would have UK coverage - one in the 10 GHz band, two in 28 GHz, and six in 32 GHz. In addition, three in 28 GHz would have varying degrees of lesser geographical coverage.

- All licences would be awarded through a single auction.
- The auction would take the form of a simple simultaneous multiple round auction ('SMRA').
- The winning bidders would be those who submitted the highest bids for each licence.
- A minimum price of £50,000 would be set for each licence.

1.3 The consultation closed on 7 September. Several responses commented on the packaging and auction design. The main points raised were:

- It would be more appropriate to offer smaller lots in the 10 GHz band in order to maximise flexibility and overall efficiency of use. There was, however, no consensus on the appropriate size of lots; for example a number of respondents suggested that two lots of 2x50 MHz be made available while another suggested five lots of 2x20 MHz.
- One respondent suggested that there should be larger lots in the 32 GHz band and if larger lots were not available the respondent would be exposed to aggregation risk.
- There was some disagreement with the proposal to defer the award of the 40 GHz band. One suggestion was to auction it, with the other bands, in three packages of 2x500 MHz.
- One respondent suggested that the packaging of lots and auction design should ensure that aggregation risk to bidders was minimised as far as possible.

1.4 In the light of these responses and further work that Ofcom has undertaken it now proposes:

- to change the packaging of the 10 GHz band, offering ten lots of 2x10 MHz, but subject to a requirement that each bidder bid for at least two such lots (i.e. a minimum of 2x20 MHz);
- to include the 40 GHz band in the award; and

- to award licences through a simultaneous multiple-round combinatorial clock auction ('combinatorial clock auction' for short).

1.5 This discussion document explains Ofcom's rationale for its revised proposals. It examines the options for packaging the bands. It sets out the proposed usage rights for 40 GHz and 10 GHz to reflect the revised packaging. It explains the key features of the combinatorial clock auction format and how it would work in practice. It also compares the relative strengths and weaknesses of the simple SMRA and combinatorial clock auction formats.

1.6 Ofcom will take account of any comments it receives in response to this discussion document in finalising its decisions on the award of these bands. It is asking for comments by 8 February 2007.

1.7 Ofcom intends to hold a stakeholder event in January 2007 to explain the proposals in this document.

1.8 Ofcom expects to publish a statement detailing its final decisions for this award, along with the information memorandum and draft regulations, early in 2007. The draft regulations will set out the auction rules and will be subject to public consultation.

Section 2

Introduction

Consultation document of June 2006

2.1 As part of Ofcom's plans to implement its strategy of ensuring optimal use of the radio spectrum it has developed a programme of awards of wireless telegraphy licences that is designed to put unused or under-used spectrum into the market. One such award under consideration is of licences for the spectrum bands 10 GHz, 28 GHz, 32 GHz and 40 GHz ('the bands'). Ofcom published a consultation document on 29 June 2006 ('the June consultation'), which set out in detail Ofcom's proposals for the award of licences to use these bands, in the light of responses it received to the Spectrum Framework Review: Implementation Plan consultation document published in January 2005.

2.2 The consultation considered a number of factors relevant to the award of the spectrum, including Ofcom's powers and approach to spectrum management, the availability and current uses of the spectrum in each band, the potential demand for spectrum in each band, the likely spectrum packaging requirements and auction design.

2.3 The key proposals set out in the June consultation for the proposed award of licences in the bands were as follows:

- All licences to be awarded through a single auction.
- The auction to take the form of a simple simultaneous multiple round auction (SMRA).
- The winning bidders to be those which submit the highest bids for each licence.
- A minimum price of £50,000 to be set for each licence.

2.4 The consultation also explained Ofcom's proposal for deferring the award of licences in the 40 GHz band.

2.5 The key proposals in the consultation for the spectrum packaging were as follows:

Band	**Spectrum packages**
10 GHz	One UK licence of 2x100 MHz
28 GHz	Two UK licences each of 2x112 MHz Three 'geographically limited' licences each of 2x112 MHz, with varying geographical coverage (see Annex 9 of the June consultation for maps illustrating this)
32 GHz	Six UK licences each of 2x126 MHz
TOTAL	**12 licences**

Consultation responses on spectrum packaging and auction design

2.6 Ofcom received several responses to the consultation that commented on the auction design and packaging of spectrum.[1] In summary these comments were:

- It would be more appropriate to offer smaller lots in the 10 GHz band in order to maximise flexibility and overall efficiency of use. There was however no real consensus about the appropriate size of lots; for example a number of respondents suggested that two lots of 2x50 MHz be made available while another suggested five lots of 2x20 MHz.

- One respondent suggested that there should be larger lots in the 32 GHz band and if larger lots were not available the respondent would be exposed to aggregation risk.

- Interest was expressed in acquiring spectrum in the 40 GHz band.

- One respondent suggested that the packaging of lots and auction design should ensure that aggregation risk to bidders is minimised as far as possible.

2.7 In the light of these responses Ofcom has given further consideration to these matters and is now putting forward amended proposals for spectrum packaging and auction design. It is still considering other points made in responses and will set out its decisions in a statement to be published early in 2007.

Purpose of this discussion document

2.8 The purpose of this discussion document is to put forward amended proposals for the packaging of some of the available spectrum and proposals for an alternative auction design, better suited to the award of these spectrum bands in the light of those amended packaging proposals and in response to comments received from stakeholders in response to the June consultation.

2.9 Ofcom is seeking stakeholders' views on these revised proposals. Ofcom will take into account any comments that it receives in response to this discussion document in formulating its decision for the award of the available spectrum. Ofcom expects to publish a statement detailing its final decisions for this award, along with the information memorandum and draft regulations, early in 2007. The draft regulations will set out the auction rules and will be subject to public consultation.

2.10 Ofcom would welcome comments or views on any aspect of this discussion document by 8 February 2007.

Structure of this discussion document

2.11 The following sections set out:

- proposed changes to packaging of the 10 GHz band and a proposal to include the 40 GHz band in the award;

[1] The responses may be found at http://www.ofcom.org.uk/consult/condocs/10ghz/responses/

- proposals for the technical conditions to apply to licences in the 40 GHz band and consideration of the technical conditions for licences in the 10 GHz band in the light of the proposed change to the packaging of spectrum in the band;

- details of an alternative auction design – a combinatorial clock auction – that Ofcom considers to be better suited to the circumstances of this award in the light of the proposed changes to spectrum packaging and comments made by stakeholders in response to the June consultation;

- a comparison of the relative strengths and weaknesses of the originally proposed simple SMRA and newly proposed combinatorial clock auction formats, in particular in relation to the issues that are likely to be factors in the auction of these particular spectrum bands.

Section 3

Spectrum packaging

3.1 Ofcom has reviewed, in the light of responses to the consultation, the appropriate way to package the available spectrum. The two changes it proposes to make are the division of the 10 GHz band into ten lots each of 2x10 MHz, although subject to a requirement that each bidder bids for at least two such lots (i.e. a minimum of 2x20 MHz), and the inclusion of the 40 GHz band in the award, divided into six lots of 2x250 MHz.

3.2 Ofcom considers that this revised approach should give more flexibility to potential bidders seeking spectrum within or across the four bands, and should increase the likelihood of an efficient auction outcome.

10 GHz

3.3 Ofcom's proposal in the June consultation was to offer the 2x100 MHz available in the 10 GHz band as a single UK-wide lot. Some responses suggested it would be more appropriate to offer smaller lots in order to maximise flexibility and overall efficiency of use. There was, however, no real consensus about the appropriate size of lots; for example a number of respondents suggested that two lots of 2x50 MHz be made available while another suggested five lots of 2x20 MHz.

3.4 In considering the appropriate size of smaller lots Ofcom has considered the radio systems that might operate in the band. The systems that have been identified, and Ofcom's assumptions on what might be regarded as the smallest practicable block sizes, are as follows:

- Fixed wireless access (FWA) (PtMP) 2x28 MHz (possibly lower)
- Backhaul (PtMP) 2x56 MHz
- Backhaul (PtP) 2x56 MHz (possibly lower)
- Programme making and special events (PMSE) 10 MHz (digital) or 20 MHz (analogue)

These assumptions are also dependant upon the technology choice for the system (i.e. modulation order, access method, antenna characteristics etc.).

3.5 There is clearly no single block bandwidth that will cater for these various systems. Ofcom is faced, therefore, with the problem of either choosing a particular block size (or combination of block sizes) that will suit some bidders better than others, or to allow the market to determine how much spectrum is awarded to each bidder using a more sophisticated auction design.

3.6 Considering this latter option, it seems that 10 MHz is the smallest assignment that any potential user is likely to want to acquire and that demand from most likely uses could be met by contiguous aggregations of 2x10 MHz lots. For example, a backhaul provider requiring 2x56 MHz could use six contiguous lots of 2x10 MHz, leaving 2x4 MHz spare which could be used for frequency separation with adjacent users.

3.7 It would seem appropriate, therefore, to offer ten 2x10 MHz lots, provided that an auction can be devised that will allow bidders to acquire contiguous aggregations of lots. Ofcom considers that a suitable auction can be devised and proposes to package the available spectrum in this way. However, as explained below in paragraph 4.7, in order to reduce co-ordination requirements it also intends to require each bidder to bid for at least two such lots (i.e. a minimum of 2x20MHz).

3.8 This revised approach to packaging the spectrum requires consideration of whether the spectrum usage rights set out in the June consultation should be modified for spectrum blocks smaller than 2x100 MHz. This is discussed in section 4.

28 GHz

3.9 In the June consultation Ofcom proposed to auction two UK lots each of 2x112 MHz and three geographically limited lots each of 2x112 MHz (the geographical coverage of each varies – see annex 9 of the June consultation). There was general support for the proposals, though Avanti Screenmedia Group and Intellect commented that the proposals would further fragment the band and be seriously detrimental to its exploitation for satellite broadband applications. Ofcom's proposals are in the main consistent with ECC/DEC(05)01, and those wishing to use the available spectrum for satellite operations may participate in the award. Also, THUS asked for one of the geographically limited lots to be changed to offer an exact complement to its existing coverage. Apart from the question whether it would be permissible to discriminate in favour of a particular operator in this way, Ofcom does not consider it practicable to modify one of the geographically limited lots to meet THUS's request. Ofcom, therefore, does not consider it necessary to change the packaging of the 28 GHz band from that in the June consultation.

32 GHz

3.10 In the June consultation Ofcom proposed six UK-wide lots, each of 2x126 MHz. There was general support for the proposal though in its response Orange considered that one lot of 2x252 MHz should be offered to avoid aggregation risk. (Orange also considered that the top one-third of the band should be retained for individually licensed fixed links.) Ofcom does not consider that the size of lots should be increased, as it is likely that the resulting lots would be too large for some bidders and this might discourage them from participating. However, Ofcom accepts that there is a degree of complementarity between lots in this band, and that under the previous auction format, bidders seeking multiple lots may have been exposed to aggregation risks. The proposed switch to a combinatorial clock auction format eliminates any aggregation risks for such bidders. Therefore, bidders seeking single 2x126 MHz lots and bidders seeking aggregations of lots should be equally able to meet their requirements.

40 GHz

3.11 In the June consultation Ofcom proposed that the award of 40 GHz should be deferred, given the apparent lack of demand, but a number of respondents expressed interest in acquiring spectrum in the band. As a result Ofcom has reconsidered its position.

3.12 One of Ofcom's spectrum management objectives is to allow, wherever possible, spectrum to be managed by the market and where spectrum is not already in use to release it as soon as practicable. In this way the market has the opportunity to find uses for the spectrum. In the consultation Ofcom pointed out that it also had to bear

in mind the resource costs of a spectrum award and if demand for the relevant spectrum did not exist incurring these costs would not be justified. The evidence available at the time of publication of the consultation document suggested that the 40 GHz band was unlikely to be used for some time. Ofcom, therefore, proposed to defer its award and to review the position within two years.

3.13 The interest shown in the band in consultation responses suggests that the market should be given the opportunity to obtain the spectrum as soon as practicable. Ofcom considers that the most efficient way of doing this would be to include the band in the same award process as 10 GHz, 28 GHz and 32 GHz: there may be scope for substitution between 40 GHz and other bands, 32 GHz in particular, and running one award process should reduce overall costs. Ofcom proposes to split the band into six UK-wide lots of 2x250 MHz, each lot being sufficiently large to allow wideband use. Bidders will be able to aggregate lots into contiguous blocks of 2x500 MHz or more.

Consequences for auction design

3.14 In the light of Ofcom's proposed changes to packaging of licences in the 10 GHz band and the responses concerning the size of licences in the 32 GHz band Ofcom considered it necessary to review the most appropriate auction design.

3.15 A particularly important consideration has been the efficiency with which the auction addresses substitutability and complementarity between lots. Where lots are substitutes or complements, auction design is important in helping bidders to switch demand between lots and manage aggregation risks across lots, so as to ensure an efficient outcome. As discussed in the June consultation, it seems likely that many bidders are likely to view the available lots, both within and across bands as substitutes and/or complements. In particular:

- PMSE bidders are likely to view lots within the 10 GHz band as substitutes;
- Bidders wishing to deploy backhaul or national fixed wireless applications are likely to view lots in the 10 GHz, 28 GHz and 32 GHz bands as substitutes.
- For wideband use, lots at 32 GHz and 40 GHz may be substitutes.

In addition, in all four bands there may be (in-band) complementarities between lots, as some bidders are likely to want contiguous spectrum endowments in excess of those available in single lots. This is likely to be a particular issue in the 10GHz band in the light of our revised proposal to package the spectrum as 10 lots of 2x10 MHz.

3.16 The simple SMRA, which was proposed in the June consultation, is very effective in addressing substitution risks between lots. However, it is much weaker at addressing aggregation risks across lots than alternative formats that would allow for combinatorial (package) bidding. Hence in the light of the changes to packaging that we are now proposing, we no longer consider the simple SMRA to be the most appropriate auction format.

3.17 Ofcom, therefore, has carefully reconsidered the issue of auction design in the light of its proposed packaging changes, and now believes that a form of combinatorial clock auction is likely to be most appropriate. This auction format is described in section 5.

Section 4

Technical conditions

4.1 Ofcom has considered whether the spectrum mask set out in the June consultation is suitable for use of equipment in the 40 GHz band, which, since the proposal was to defer the award of the band, was not covered in the consultation, and also for use of equipment in blocks smaller than the 2x100 MHz that was proposed for 10 GHz.

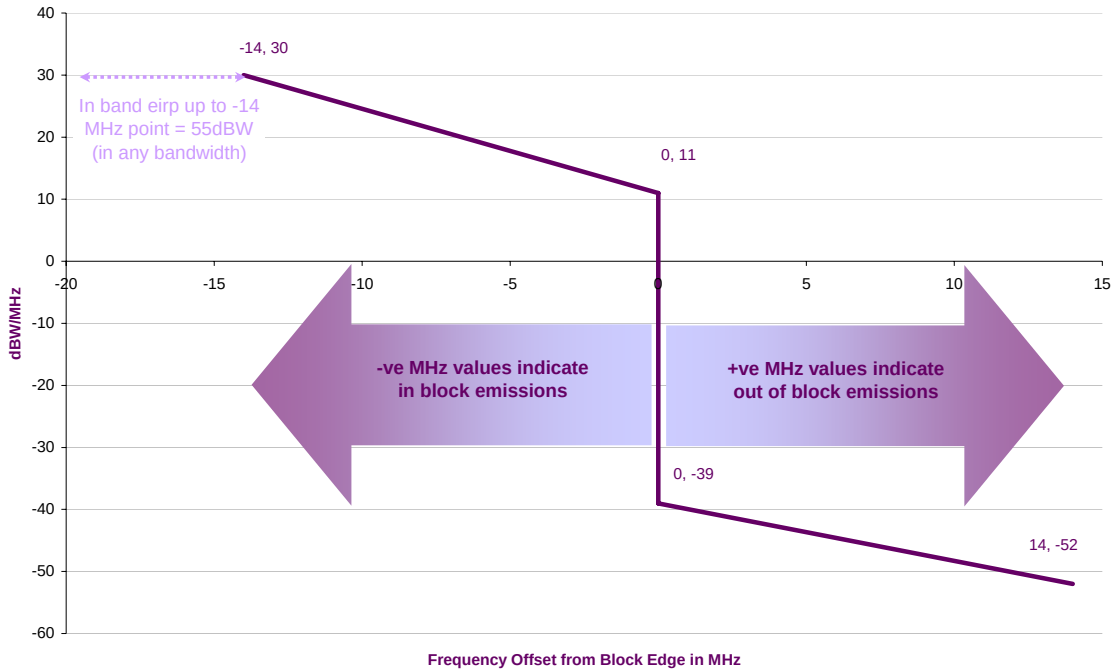
Spectrum mask for 40 GHz

4.2 The spectrum mask proposed for 10 GHz, 28 GHz and 32 GHz is defined by the points listed in the table below, with linear interpolation between them.

Frequency offset from block edge (-ve in block, +ve out of block)	EIRP
< -14 MHz	55 dBW (in any measured bandwidth)
-14 MHz	30 dBW/MHz
Block edge (when arrived at from in-block)	11 dBW/MHz
Block edge (when moving out-of-block)	-39 dBW/MHz
+14 MHz	-52 dBW/MHz

The mask is shown graphically in Figure 1.

Figure 1. Spectrum mask proposed for 10 GHz, 28 GHz, 32 GHz and 40 GHz



4.3 Ofcom considers this spectrum mask to be appropriate for 40 GHz. The mask derives from the mask shown in ECC Report 32[2], which actually took the block edge mask methodology developed for 40 GHz multimedia wireless systems and applied it

[2] http://www.ero.dk/documentation/docs/doc98/official/pdf/ECCREP032.PDF

to lower frequency bands such as 28 GHz. Ofcom believes this mask is appropriate from a technology neutral point of view.

Effect of revised packaging of 10 GHz

4.4 The spectrum mask proposed in the June consultation defined the permitted in-block and out-of-block emission limits for a licensee holding all the available 2x100 MHz in the 10 GHz band. Since Ofcom is now proposing that the available spectrum in this band be packaged as ten lots of 2x10 MHz it is necessary to consider in addition what boundary conditions should apply between blocks within the band.

4.5 The 2x10 MHz lots proposed for the band are designed to allow aggregation into what bidders may consider desirable paired blocks, for example 2x30 MHz, 2x50 MHz, 2x60 MHz or 2x100 MHz. Where blocks of 2x20 MHz or more are obtained in the auction the previously proposed mask remains appropriate, though for a block of 2x20 MHz permitted in-band eirp would be no more than 24 dBW/MHz, and even then only at the very centre of the block.

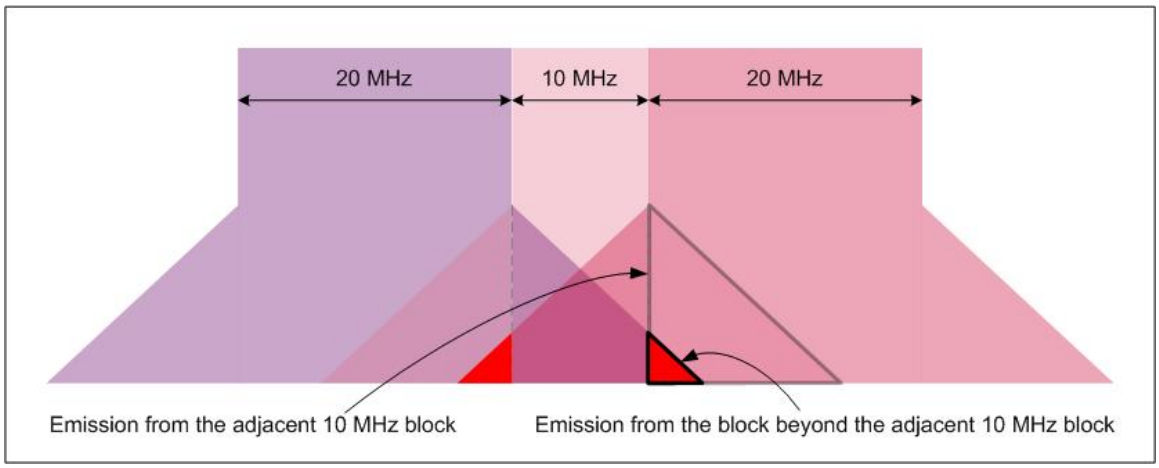
4.6 Figure 2 illustrates how the spectrum mask would apply to blocks of various sizes, i.e. 20 MHz, 30 MHz and 50 MHz. For blocks of 20 MHz the eirp will be constrained by the mask across the entire block, with the maximum permitted eirp being 24 dBW/MHz at the centre of the block, falling to 11 dBW/MHz at the block edges.

Figure 2. Illustration of the application of the spectrum mask to blocks of differing size

4.7 The effect of applying the mask to blocks adjacent to a 10 MHz block is illustrated in Figure 3. It will be seen that there is an overlap in emissions from each such block not only into the 10 MHz block but also into the block beyond. This applies on both sides of the 10 MHz block, so that each adjacent block might receive out-of-block emissions both from its neighbouring 10 MHz block and from the block beyond that. This could necessitate co-ordination with two operators rather than just one. In order

to avoid this possibility Ofcom is proposing to set 2x20 MHz as the minimum amount of spectrum for which bids will be accepted.

Figure 3. Illustration of the effect of emissions from blocks adjacent to a 10 MHz block



Note: the size of the adjacent blocks does not affect the situation. 20 MHz blocks are shown to give a sense of the scale.

Section 5

Combinatorial clock auction format for this award

Introduction

5.1 This section describes how a combinatorial clock auction format would work in the award of spectrum in the 10 GHz, 28 GHz, 32 GHz and 40 GHz bands. Annex 2 describes in more detail the main features of this auction format and some key auction rules.

5.2 The combinatorial clock auction proposed here brings together the simplicity of a clock auction with the superior efficiency properties of a combinatorial SMRA when some bidders consider lots to be complements. With this format, much of the benefit of a combinatorial SMRA can be achieved without onerous requirements on bidders to make extensive bids, or the need to run complex pricing algorithms each round. Ofcom expects that, like the simple SMRA proposed in the June consultation, the combinatorial clock auction will be run electronically, with remote bidding.

5.3 Ofcom proposes a two-stage approach to allocating and assigning lots.

- In the first stage – **the principal auction stage** - bidders will bid for the amount of spectrum that they want in each frequency band, but without specifying the specific frequencies that they would most like to win;

- In the second stage – **the final assignment stage** - successful bidders from the first stage can express any preference they might have for particular frequencies within each frequency band.

5.4 In a simple clock auction, all the lots are of a single category; they are sufficiently close substitutes that bidders would be equally happy to win any one of them. The auction proceeds in rounds, with the auctioneer announcing a price per lot at the beginning of each round (i.e. the clock price, which is the same for all lots), and bidders responding by saying how many lots they would like to buy at that price. As the price announced by the auctioneer increases, demand falls (bidders not being allowed to increase their demand from round to round). Eventually demand falls to the point where it is less than or equal to supply. At this point the auction ends, with the bidders who remain winning the number of lots that they bid for in the final round and paying the final ‘clock price’ for each lot that they won.

5.5 The combinatorial clock auction adopts a similar procedure but with a number of categories of lots on offer, each category with its own ‘clock price’. In each round, bidders state the number of lots in each of the different categories that they would most like to buy at the stated prices. Prices of categories where demand for lots exceeds supply are increased from round to round; prices of categories where demand for lots is less than or equal to supply remain constant. The combinatorial clock auction ends when demand for every category has fallen to less than or equal to the number of lots available.

The combinatorial clock stage

5.6 In this auction there would be seven categories of spectrum that bidders would be able to bid for, as shown in the table below:

Category of spectrum	*Bandwidth per lot*	*Number of lots available*
10 GHz national	2 x 10 MHz	10
28 GHz national	2 x 112 MHz	2
32 GHz national	2 x 126 MHz	6
40 GHz national	2 x 250 MHz	6
28 GHz sub-national 1	2 x 112 MHz	1
28 GHz sub-national 2	2 x 112 MHz	1
28 GHz sub-national 3	2 x 112 MHz	1

5.7 At the beginning of each round of the auction, Ofcom would announce a price per lot for each category of spectrum. Each bidder would then be required to fill in and submit (electronically, online) a bid form stating how many lots of each category it was most interested in buying at those prices. (The bid form would automatically work out the corresponding total amount of the bid.)

5.8 The table below illustrates how a bidder might fill in a bid form at prices that Ofcom might set at the start of a round. (Note that these prices are purely illustrative.)

Category of spectrum	*Bandwidth per lot*	*Number of lots available*	*Price per lot*	*Number of lots bid for*	*Total price*
10 GHz national	2 x 10 MHz	10	£50,000	**5**	£250,000
28 GHz national	2 x 112 MHz	2	£300,000	**1**	£300,000
32 GHz national	2 x 126 MHz	6	£250,000	**0**	£0
40 GHz national	2 x 250 MHz	6	£100,000	**2**	£200,000
28 GHz sub-national 1	2 x 112 MHz	1	£30,000	**0**	£0
28 GHz sub-national 2	2 x 112 MHz	1	£20,000	**0**	£0
28 GHz sub-national 3	2 x 112 MHz	1	£50,000	**0**	£0
				Total bid:	**£750,000**

5.9 Each bid submitted would be an irrevocable, indivisible and stand-alone commitment to purchase the stated number of lots of each category at the total bid price.

- Irrevocable in the sense that the bid would remain valid throughout the auction, notwithstanding any other bids that the bidder may subsequently make.
- Indivisible in the sense that that the bid stands or falls as a whole – the bidder can not be forced to buy only a subset of the lots listed.
- Stand-alone in the sense that multiple bids from a single bidder will not be combined – at most one bid from each bidder will be a winning bid.

5.10 The prices per lot in the first round of the auction would be the reserve prices (see Annex 2). In later rounds Ofcom would increase the price of categories of lot that were in excess demand (where the total number bid for by bidders in the previous round exceeded the number available) but would leave unchanged the price of each category of lot where demand was less than or equal to available supply (where the total number of lots bid for was less than or equal to the number of lots available).

5.11 As prices increased we would expect to see demand reduce, until eventually demand for each and every category of lot was less than or equal to the available supply (the

number of lots available). Once this had happened this first stage of the auction would end.[3]

5.12 If at the end of this first stage the total number of lots of each category that were bid for in the final round was the same as the number available (so that demand exactly equalled supply), then the bidders that submitted those bids would be the winning bidders, and they would ultimately be assigned an amount of spectrum equal to the amount that they included in their final round bids. The exact frequencies that they would be assigned would be determined through the 'final assignment' stage of the auction described below. The 'base price' that each bidder would have to pay for its licence would be the total amount of its final bid.

5.13 Alternatively the outcome of the final round of the combinatorial clock stage might be that there were some categories of lot for which final demand was less than the available supply. In this case a further auction stage would be required to determine the winning bidders and their winning bids. This further stage would consist of a single round of 'best and final offer' bids.

The best and final offers stage

5.14 The purpose of the 'best and final offers' stage is to allow bidders (all bidders) the opportunity to express their willingness to pay for combinations of lots which they would be happy to win even though they did not bid on them during the first, combinatorial clock stage of the auction (for example because in each round they preferred another combination of lots at the prices set by the auctioneer). A combination of these bids may allow the auctioneer to assign more of the available spectrum than was achieved at the end of the first, combinatorial clock stage of the auction, and hence achieve a more efficient assignment.

5.15 The form of 'best and final offer' bids is the same as for bids made during the first, combinatorial clock stage of the action, in the sense that they consist of a statement of the number of lots of each category that the bidder would like to win, and the total amount that the bidder would be willing to pay to win that combination of lots. However, in this case Ofcom would not pre-specify prices for lots in each category.

5.16 'Best and final offer' bids can be made by all bidders that participated in the first, combinatorial clock stage of the auction, and each bidder can submit a number of such 'best and final offer' bids. However, all such 'best and final offer' bids must be compatible with the bids that the bidder made during the first stage. What this means, in practice, is that the total bid amount in all 'best and final offer' bids must be no greater than the maximum amount that the bidder could have bid in the first stage for the combination of lots in the bid (recalling that bidders may only decrease, not increase their demand from round to round, and so there will come a point at which they will no longer be eligible to bid for a particular combination of lots). Note, however, that this constraint does not limit the amount that bidders who submitted bids in the final round of the first stage can bid for combinations of lots on which they would still be eligible to bid following the final round.

5.17 Having received all of the 'best and final offer' bids, Ofcom would then identify the feasible combination of such bids that maximised the total amount bid for the available spectrum. That combination would then be the winning combination of bids,

[3] To ensure that bidders did not hide their demand at any time during this first stage of the auction, there would be an activity rule which would mean that bidders could only reduce and not increase their demand from round to round.

and the bids that make up that combination, the winning bids.[4] Ofcom would also determine the 'base price' to be paid by each winning bidder using a quasi second price rule – the winning bidders would in general not pay the amount that they bid, but rather the minimum amount necessary to ensure that no losing bidder would be able to complain that they had, through their bids, expressed a willingness to pay more.[5]

5.18 To simplify the process of submitting 'best and final offer' bids that are compatible with bids made during the first stage of the auction, Ofcom is minded to allow bidders to submit 'best and final offer' bids during the first, combinatorial clock stage. Bidders would be able to submit a 'best and final offer' bid - for any combination of lots of interest to them - in the last round of the combinatorial clock stage in which it was open to them to bid on that combination of lots (because after that round they would have to increase their eligibility in order to bid on that combination, which would not be permitted under the auction activity rules). Such 'best and final offer' bids would only come into play if a subsequent 'best and final offers' round was required – they would play no role in determining the outcome of the combinatorial clock stage itself.

The final assignment stage

5.19 Once the winning bidders, and the amount of spectrum of each category that is to be assigned to them, has been determined through the combinatorial clock and, if required, 'best and final offer' stages, the auction would move into the 'final assignment' stage. The purpose of the 'final assignment' stage would be to determine which specific frequencies within each band are to be assigned to each winning bidder.[6]

5.20 The 'final assignment' stage would be a single round sealed bid process, and would allow the winning bidders to make a number of 'top-up' bids, expressing any additional amount that they would be willing to pay, over and above the base price already determined, if they were to be assigned particular frequencies within each band. Ofcom would then determine the specific frequencies within each band to be assigned to each winning bidder, so as to maximise the total value of the top-up bids accepted, while at the same time ensuring that each and every winning bidder received contiguous spectrum within each band.

5.21 For example, it may be that there are two winning bidders for the two UK-wide packages in the 28 GHz band, each winning one lot. Each of these winning bidders would then be given the opportunity to make a top-up bid against each of the two available packages – the upper frequency block and the lower frequency block. If they both made a top-up bid for the same frequency block then the bidder that made the larger top-up bid would win that block, and the other bidder would win the other block. In this case the bidder that made the larger top-up bid would pay the amount of that bid in addition to the base price for their licence, whereas the other bidder would only pay the base price.

[4] If there were to be more than one combination of such 'best and final offer' bids that achieved the same maximum value then Ofcom would use a method of random selection to determine which such combination was the winning combination.
[5] We propose a quasi second price rule here to reduce the risk that bidders will be overly conservative when making 'best and final offer' bids, which could lead to an inefficient outcome.
[6] In the case of the geographically limited rights of use in the 28 GHz band there will be only one lot within each category and hence no need to include these lots in the final assignment stage since the frequencies to be assigned to the winning bidders will already have been determined.

5.22 A similar process would be followed for each of the available frequency bands in which more than one bidder had been successful in securing spectrum.

5.23 Further details of the proposed combinatorial clock auction design and rules can be found in Annex 2.

Section 6

Comparison of combinatorial clock auction and simple SMRA

Introduction

6.1 Simple SMRA and combinatorial clock auctions should both perform well where lots are substitutes and competition is reasonably strong. However, the combinatorial clock auction has particular strengths compared with a simple SMRA, notably in handling the situation where lots within and across bands may be complementary.

6.2 This section describes the key issues that need to be addressed in the auction design for this award and compares the relative strengths and weaknesses of the simple SMRA and combinatorial clock auctions in dealing with these issues.

Common value uncertainty

6.3 Ofcom considers that there is likely to be common value uncertainty in this auction. This is because some bidders are likely to want to use this spectrum to provide similar services to common markets. Under these conditions, bidders may benefit from being able to observe how their rivals' demand changes in response to prices. The efficiency of the auction should be improved if bidders are able to observe the behaviour of their rivals over the course of multiple rounds (subject to concerns about not facilitating collusion), relative to participating in a single round sealed bid process.

6.4 Both the simple SMRA and the combinatorial clock auction are open multi-round processes, so both formats should offer benefits in terms of reducing common value uncertainty. Arguably, the combinatorial clock format may offer the greater information benefits, as the inclusion of best and final offers throughout the clock auction may provide richer information than the simple SMRA about bidders' willingness to substitute demand across lots.

Aggregation risk

6.5 Aggregation risks are a significant concern in this award. For some bidders, the value that they place on acquiring bundles of lots will be higher than the sum of the values of the individual lots, owing to synergies between lots. Moreover, some bidders will likely have minimum requirements for spectrum within bands which can only be met by acquiring multiple lots within the same band, often on a contiguous basis. Under any auction format where bidding takes place on individual lots such bidders will be exposed to aggregation risks.

6.6 Aggregation risks are generally considered undesirable as they discourage bidders from bidding their true value for available spectrum. In the worst case bidders may not even participate in the auction owing to the risk that they might win only a subset of the lots they require which would be insufficient to provide services. This may undermine the efficiency of the auction outcome, as bidders with lower value for the available spectrum may instead be successful in the auction.

6.7 Although the secondary market provides some insurance against aggregation risks this is not perfect as:

- it might be that all other lots have been sold in large enough packages, so there are no other lots to complement the 'leftovers' being sold; or

- the secondary market may be subject to frictions due to transactions costs or bargaining inefficiencies.

Aggregation risk: simple SMRA

6.8 The simple SMRA is not effective at addressing aggregation risks. Bidders have some flexibility to monitor the likelihood of their winning particular bundles of lots over multiple rounds. However, this flexibility diminishes towards the end of the auction, as it can be difficult for bidders to reduce the number of lots on which they are bidding and to exit the auction without winning any lots at all.

6.9 Aggregation risks can be diminished by packaging spectrum into larger bundles that reflect the requirements of bidders. In the previous award design, using the proposed packaging and a simple SMRA format, Ofcom judged that the aggregation risks bidders would still be exposed to were sufficiently modest that they would be unlikely to compromise the efficiency of the award outcome. However, the consultation responses produced new information about bidder requirements and have prompted changes to the spectrum packaging. Together, these suggest that aggregation risks for some bidders may be substantial:

- At least one respondent to the consultation expressed interest in purchasing two complementary lots in the same frequency band under the previous packaging approach.

- The division of the 10 GHz band into ten lots of 2x10 MHz will mean that many bidders for this spectrum will likely have demand for multiple contiguous lots.

6.10 Ofcom considers that a simple SMRA may not adequately alleviate these aggregation risks. Therefore, there is a strong case for allowing bidders to submit bids for packages of lots, rather than only bidding separately on individual lots. However, integrating package bidding into a standard SMRA format is problematic, as it places onerous requirements on bidders to determine bids for a number of mutually exclusive bid options in each round and requires the auctioneer to run complex pricing algorithms each round to determine individual lot prices.

Aggregation risk: combinatorial clock auction

6.11 The combinatorial clock auction proposed here brings together the simplicity of a clock auction with the superior efficiency properties of a combinatorial SMRA when some bidders consider lots to be complements. As with a combinatorial SMRA, the use of package bidding eliminates aggregation risks. However, onerous requirements on bidders to make extensive bids in each round are diminished and the approach to determining clock prices for lots over multiple rounds is straightforward.

6.12 All package bids are mutually exclusive. It is not possible for a bidder to win only part of a package on which it bids; bids stand or fall in their entirety. Therefore, bidders can fully express the value of synergies between lots and are never exposed to being stranded with lots that they do not want.

Threshold problem

6.13 One downside of package bidding is that facilitating aggregation for larger bidders may introduce a 'threshold problem'. This occurs where small bidders (wanting few lots) find it difficult to organise themselves into implicit consortia capable of displacing larger bidders (wanting to aggregate many lots), even though their collective valuation may be higher.

6.14 In any auction with package bidding, such as the combinatorial clock auction, the question arises whether individual small bidders will have sufficient incentives to raise bids to levels where they collectively displace aggregating bidders. There may be a free-rider problem in that if one or more small bidders raise their bids this may benefit all small bidders by displacing the package bidder. This means that a small bidder will have an incentive not to raise its bid even though it may have a higher value on the lots it wants to win. This could result in inefficiency if the combined value of small bidders exceeds that of the package bidder. However, this needs to be balanced against the potentially severe aggregation risks that may be faced by the large bidder.

6.15 Ofcom considers that the benefits from mitigating aggregation risks created by using a combinatorial clock format for this award significantly outweigh any costs related to increased threshold risks. Releasing information about best and final offers each round may also facilitate bidding by implicit consortia of smaller bidders, possibly reducing threshold problems.

Complexity

6.16 Other things being equal, simpler auctions are preferable from both the perspective of bidders and Ofcom. For bidders, the more straightforward and transparent the auction is, the more likely they are to develop an efficient bidding strategy, and the less likely they are to make mistakes. Simpler auctions may also reduce participation costs for bidders and administrative costs for Ofcom.

6.17 One of the main attractions of the simple SMRA is that it is relatively straightforward to implement and easy for bidders to understand. However, in auctions where there are many lots an SMRA with package bidding may become very complex if bidding on the full range of possible packages is permitted. Even if bidding in the auction were restricted to packages of contiguous lots there would still be a large number of possible package bids that could be made in each round of the auction.

6.18 Adopting a combinatorial clock auction avoids the complexity of an SMRA with package bidding. First, by using generic lots the number of possible packages that can be bid on in the clock stage is significantly reduced. Second, bidders are only required to make one bid each round for their most preferred package of lots, plus optional best and final offers for a limited number of other packages in rounds where they reduce eligibility. Third, prices are set round-by-round using a simple and transparent process.

6.19 The combinatorial clock auction is also strategically simple for bidders. In a simple SMRA bidders must condition their bids to manage aggregation risks, potentially leading them to bid less than their true value and/or avoid bidding on lots where the risk of being stranded without complementary lots is greatest. Furthermore, as only the highest bids on specific lots are ultimately binding there may be strong incentives for strategic bidding (see below). By contrast, there are strong incentives for

straightforward bidding with the combinatorial clock format, as any bid submitted in any round could potentially become a winning bid.

Strategic bidding

6.20 Depending on the structure of supply and demand for lots, SMRAs may be vulnerable to strategic behaviour which can distort the auction outcome and reduce efficiency. Examples of strategic behaviour which have affected previous spectrum awards that used an SMRA format include:

- Code bidding / signalling – using bid amounts to signal bidding intentions to other bidders for the purposes of tacit collusion;
- Price manipulation – deliberately bidding up the price of specific lots with the aim of disadvantaging competitors with less flexible bid strategies;
- Punishment – encouraging other bidders to withdraw demand for specific lots by threatening to drive up the price of other lots that they also want;
- Parking – bidding on lots which the bidder ultimately does not want, so as to retain eligibility to switch demand to other lots. Bidders may do this for two reasons: to keep the prices on desired lots from increasing too quickly and to maintain the flexibility to punish competitors.

6.21 The simple SMRA, especially if augmented with rules that permit bid withdraws or switching so as to mitigate aggregation risks, may be particularly vulnerable to strategic bidding. For this award, there is considerable uncertainty over the level of demand and relative value of different types of lots. This makes it difficult to pre-judge the appropriate level of eligibility point ratios between lots in the different bands.

6.22 The combinatorial clock format should be less vulnerable to strategic manipulation than the simple SMRA. As all bids are potentially binding the strategic incentive to bid on unwanted lots during intermediate rounds of the auction is largely eliminated. One possible concern is that the use of best and final offers could introduce opportunities for code bidding, but this can be prevented using appropriate rules on how such bids are displayed to other bidders.

Strategic demand reduction

6.23 SMRAs are potentially vulnerable to strategic demand reduction. Specifically, bidders may be tempted to reduce their demand in the auction with the objective of achieving a lower price per lot than would be possible if they bid strictly on the basis of their valuation. This may reduce the efficiency of the auction outcome.

6.24 Strategic demand reduction is most likely to be a problem in auctions where there a few bidders seeking many lots and demand is not greatly in excess of supply. Such a scenario appears possible for this award. It is relevant to both the simple SMRA and combinatorial clock auction formats. However, clock auctions may be more vulnerable to strategic demand reduction, as with uniform pricing of lots there is a more direct relationship between reducing demand and the price paid.

6.25 Nevertheless, Ofcom does not consider the risks associated with strategic demand reduction to be sufficient to suggest not using a combinatorial clock auction. Incentives for strategic demand reduction are largest for those wanting most lots, so

this may work to reduce concentration in downstream markets for goods and services. Clearly this is only relevant where winners are likely to compete in the same economic markets but this appears possible for this band. Although strategic demand reduction may be poor for efficiency in the narrow sense of allocation within the auction relative to the valuations of bidders, it may be good for efficiency in the wider sense of reducing any incentives to concentrate lots to gain downstream market power. Where bidders are downstream competitors the overall impact of strategic demand reduction on consumer welfare is ambiguous.

6.26 It is also difficult for bidders to predict what the effect of reducing demand will be on the price paid, as this may not necessarily be determined solely by the outcome of the clock auction but rather by optimising over all bids received in the course of the auction in the best-and-final-offers stage.

6.27 In the event that the award is competitive, this will anyway tend to reduce the incentive for strategic demand reduction, as winners are unlikely to receive a large proportion of the available lots. Even if the award is not particularly competitive there may be opportunity to reduce incentives for strategic demand reduction by ending the clock stage early and allowing for a greater role for best and final offers (see discussion of weak competition below).

Weak competition

6.28 SMRA formats may be vulnerable to weak competition, either as a result of bidder asymmetries (which discourage perceived weaker bidders from participating) or 'demand fixing' where bidders co-ordinate prior to the auction in an attempt to eliminate excess demand and thus achieve low prices. Bidder asymmetries are not obviously a concern for this auction: there is no particular reason to expect that there will be some bidders who are anticipated to be systematically stronger and more likely to win than others. However, there is uncertainty over the level of demand.

6.29 Both the simple SMRA and combinatorial clock auctions are potentially vulnerable to demand fixing. In both cases, measures to restrict transparency – such as hiding the number or names of applicants – may help to prevent coordination. Alternatively, the combinatorial clock auction could be terminated early (i.e. before demand is reduced to less than equal supply) and concluded with a combinatorial sealed bid round with relaxed activity rules. In addition, payments for winning bids could be determined by a pay-what-you-bid rule, rather than the quasi-second price rule.

6.30 Modifications to auction rules to deal with weak competition could be made conditional on the aggregate level of initial eligibility across all bidders, which in turn depends on the number of bidders participating and their deposit levels. However, there would need to be sufficient time between bidders' making deposits and the start of the auction so that the auctioneer could announce which auction rules would apply and bidders could make appropriate preparations. This could leave the process vulnerable to manipulation by bidders seeking to fix the level of demand in advance of the auction.

Unsold lots

6.31 Unsold lots are only a concern if they occur because bidders have been unable or unwilling to express the full value of their demand for different packages of lots, owing to spectrum packaging or auction design. If unsold lots occur purely as a result

of lack of market demand this is an unavoidable outcome and does not affect the efficiency of the award.

6.32 A simple clock auction would not be a good mechanism for awarding this spectrum as there would be a significant risk of unsold lots, despite there being potential demand for them. Trying to apply a uniform price for all lots of a given category may lead to unsold lots if demand drops below supply at the end of the clock auction. This may result in an inefficient allocation. For example, there might be individual bidders willing to buy the unsold lots at less than the final clock price. More generally, it might be possible to package unsold lots with additional lots and allocate these packages to bidders with a greater willingness to pay for the package than the opportunity cost to other bidders.

6.33 The combinatorial clock format largely eliminates the problem of inefficiently unsold lots through the use of the ‘best and final offers’ stage. This stage allows bidders to express their preferences for many different packages. The best and final offers are considered to see if there might be a more efficient allocation of the available spectrum in the event that there were unallocated lots at the end of the clock stage.

Section 7

Next steps

7.1 While this is not a formal consultation, Ofcom invites written views and comments on the proposals and issues raised in this document. It will take account of any comments it receives in finalising its decisions on the award of these bands. Comments should be sent to Ofcom by 8 February 2007 (see annex 1 for details).

7.2 Ofcom will carry out a stakeholder event to cover the issues and proposals in this document in January 2007.

7.3 Ofcom expects to release a statement detailing its final proposals for this spectrum award along with draft regulations and an Information Memorandum early in 2007. The draft regulations will set out the auction rules and will be subject to public consultation. An award would then be planned to take place later in the year.

Annex 1

Responding to this discussion document

How to respond

Ofcom invites written views and comments on the issues raised in this document by 5pm on **8 February 2007**.

Ofcom intends to publish the responses it receives. Respondents should specify if they wish part or all of the response to remain confidential.

Please can you send your response to joe.sonke@ofcom.org.uk. If you want to discuss the issues and questions raised in this consultation you may contact Joe Sonke on 020 7783 4345.

Annex 2

Further details of proposed combinatorial clock auction design and rules

Introduction

A2.1 In this annex we describe in more detail the main features of the proposed combinatorial clock auction and the key rules that would apply to the award of this spectrum.

Eligibility, deposits and reserve prices

A2.2 Lots in each category are assigned a number of eligibility points. Ofcom intends to set eligibility points to broadly reflect the relative size of lots and potential attractiveness of different frequency bands. Its provisional approach is set out in Table A1.

Table A1: Description of lots, eligibility points and reserve prices

Band	Category	Number of lots	Spectrum endowment	Eligibility points per lot	Reserve price
10 GHz	A: 10 GHz	10	2x10 MHz	1	£10,000
28 GHz	B: 28 GHz national	2	2x112 MHz	6	£60,000
	C: 28 GHz licence 1	1	2x112 MHz	2	£20,000
	D: 28 GHz licence 2	1	2x112 MHz	1	£10,000
	E: 28 GHz licence 3	1	2x112 MHz	3	£30,000
32 GHz	F: 32 GHz	6	2x126 MHz	6	£60,000
40 GHz	G: 40 GHz	6	2x250 MHz	3	£30,000

A2.3 In determining the eligibility points for lots in each category a 2x10 MHz lot in 10 GHz was taken as the basic unit. For the lots in each of the other categories Ofcom took into account the spectrum endowment and the relative attractiveness of the spectrum. It based its assessment of attractiveness on a specially commissioned market study by Quotient and Indepen undertaken towards the end of 2005. This found that there was most interest for spectrum in the 10 GHz band, with parties expressing interest in spectrum for use in backhaul, FWA or PMSE applications. Potential bidders wishing to obtain spectrum for FWA applications and for backhaul also expressed interest in the 28 GHz band. It found that there was less interest in acquiring spectrum in the 32 GHz band than in the 10 GHz or 28 GHz bands. It also found virtually no interest in 40 GHz, though responses to the June consultation showed that some interest has now emerged. In view of these apparent differences in the potential attractiveness between bands Ofcom has not set eligibility by simply multiplying up in proportion to the spectrum endowment but used weighting factors. National 28 GHz lots have been valued at 54% of 10 GHz (on a per MHz basis), 32 GHz lots at 47% and 40 GHz lots at 12%. The geographically limited 28 GHz licences have been valued in relation to a national licence accordingly to the scope of their geographic coverage, e.g. licence 2 has the smallest coverage.

A2.4 Bidders start the auction with an initial level of eligibility based on their deposit submitted at the application stage. The minimum level of deposit will be £50,000,

which corresponds to an eligibility of 5 points. Thus all bidders will start the auction with at least 5 eligibility points. For each additional £10,000 of deposit, bidders will start the auction with an additional 1 eligibility point. Thus a bidder that submitted a deposit of £120,000 would start the auction with 12 eligibility points. A bidder could bid for all the available lots. In order to do so it would need 82 eligibility points and it would have to submit an initial deposit of £820,000.

A2.5 Deposits are required in order to provide an adequate deterrent to default after the auction. It is possible that the prices of lots in the auction could rise to a point where the initial deposits are a sufficiently small proportion of bids being made that they are no longer an adequate deterrent to default. To prevent this from happening, Ofcom intends to introduce rules which would require bidders to top up their deposits at certain points during the combinatorial clock auction depending on the amount of their bids.

A2.6 There is a reserve price per lot for each category, which is based on the number of eligibility points per lot. The reserve price for each lot has been provisionally set at £10,000 per eligibility point. For example, the reserve price per lot in the 10 GHz band, where each lot is worth 1 point, is £10,000; and the reserve price per lot in the 32 GHz band, where each lot is worth 6 point, is £60,000. A full list of provisional reserve prices is provided in Table A1.

Clock prices and bid increments

A2.7 There are seven separate price clocks, one for each category of lots. The clock prices in the first rounds are set equal to the reserve prices.

A2.8 In subsequent rounds, clock prices of categories of lots in excess demand are increased, being set equal to the price for that category in the previous round plus a bid increment. Prices of categories of lots where there is no excess demand are unchanged from the previous round. For example, in Category A where there are ten lots, if aggregate demand is less than or equal to ten, then the price will stay the same in the next round; if aggregate demand exceeds ten, then the price will be increased by a bid increment.

A2.9 Different bid increments may be used for different categories, and the size of the bid increment may vary from round-to-round, at the discretion of the auctioneer. In setting the appropriate bid increment, the auctioneer will take into account factors such as the level of excess demand by category; relative prices across categories, the ability of bidders to express preferences for different numbers of lots at different price points and the pace of the auction.

Activity rules and bid submission in the combinatorial clock stage

A2.10 In each round of the combinatorial clock stage, bidders submit a single bid for their most preferred package of lots across the seven categories, based on the current clock prices.

A2.11 There is an activity rule which applies throughout the auction. In each round, the sum of eligibility points associated with the component lots in a bidder's preferred package bid cannot exceed their current eligibility. In the first round, a bidder's initial eligibility is determined by the level of its deposit, as described above. In subsequent rounds, eligibility is determined by the level of a bidder's activity in the previous round. Activity is measured by the total number of eligibility points associated with the component lots in a bidder's preferred package bid.

A2.12 The activity rule ensures that aggregate demand in the auction – as measured by the sum of eligibility points associated with all preferred package bids – cannot increase[7] (except temporarily following one or more bidders playing a waiver in the previous round – see below).

A2.13 In the case that a preferred package bid entails a reduction in eligibility relative to the previous round, the bidder has the option to submit a limited number of **best and final offers** in the same round. These best and final offers would only be possible on packages on which:

- bids cannot be made in subsequent rounds due to the reduction of eligibility implied by the bidder's choice of most preferred package; and
- bids would have been possible in the previous round.

A2.14 Best and final offers must be made at prices not less than the sum of reserve prices and not exceeding the sum of current clock prices associated with the component lots. Therefore, they cannot be used as an alternative to bidding in the next round and so subvert the price discovery process.

A2.15 A simple example makes this clear. Suppose that in round N, the prices of lots in Categories A, B and F are £20,000, £100,000 and £100,000 respectively. Now suppose that a bidder submits a bid for six lots in Category A and two lots in Category B. Since the eligibility points for a lot in each category is one and six respectively its total activity and eligibility in the next round is 18 points. Now suppose that the price of lots in Category A is increased to £25,000 but the price of lots in Categories B and F remains unchanged at £100,000 in round N+1. Then consider two cases of bids that may be made in round N+1:

- Case 1 - the bidder continues to bid on six lots of A and two lots of B;
- Case 2 - the bidder reduces its demand to three lots of A but maintains its demand for two lots of B.

In the first case, activity is maintained at the previous level, so there are no best and final offers that can be made.

In the second case, activity declines from 18 points to 15 points, so eligibility falls and the bidder will not be able to bid again for any package of lots across any of the seven categories with aggregate eligibility of between 16 and 18 points inclusive. The bidder may enter best and final offers for packages of lots with aggregate eligibility in this range. For example, the bidder could submit best and final offers for packages such as:

- five lots of A and two lots of B at a price not exceeding £325,000 (5*£25,000 + 2*£100,000);
- ten lots of A and one lot of B, at a price not exceeding £350,000 (10*£25,000 + £100,000);
- six lots of A and two lots of F, at a price not exceeding £350,000 (6*£25,000 + 2*£100,000); and

[7] In line with standard economic theory one would not expect demand to increase following an increase in prices.

- three lots from category F, at a price not exceeding £300,000 (3*£100,000)

A2.16 Depending on the reduction in eligibility, it is possible that there could be a very large number of packages of lots that could be included among the set of best and final offers. Ofcom provisionally intends to cap the number of best and final offers that can be made in any one round at twelve offers. This cap is appropriate in order to limit the complexity of bid submission on a round-by-round basis and thus support a smooth progression of the auction.[8]

A2.17 Bidders are under no obligation to make use of best and final offers. However, in the event that there are otherwise unallocated lots at the end of the combinatorial clock stage, they can improve their chances of winning additional lots through making best and final offers.

A2.18 Best and final bids are not relevant for calculating eligibility in the subsequent round of the combinatorial clock stage; only the most preferred bid is considered for that purpose.

Waivers

A2.19 Waivers can be played in the combinatorial clock auction instead of entering a bid. By playing a waiver, bidders avoid losing eligibility in the next round if they fail to enter a bid. Bidders that play a waiver forego the opportunity to make a most preferred bid or submit best and final offers in the round in which they play it.

A2.20 Bidders start the auction with two waivers. Additional waivers may be granted to all bidders at the discretion of the auctioneer. Waivers can be deployed in any round of the combinatorial clock auction except round 1. Waivers would be played automatically by the bidding system if a bidder failed to submit a bid decision (subject to these limitations).

A2.21 The combinatorial clock stage will not finish after a round in which at least one waiver was played. In the event that there was excess demand in the previous round, prices will be increased as previously described. If there was no excess demand for any category of lots, prices remain the same and the combinatorial clock stage continues.

End of the combinatorial clock stage

A2.22 At the end of each round of the combinatorial clock auction, the auctioneer determines whether there is excess demand for any category of lots given the most preferred packages stated by bidders. If there is no excess demand in any of the seven categories and no waivers were played in the previous round, the combinatorial clock stage ends.

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[8] Alternatively, it would be possible to defer the entry of best and final bids until the end of the clock stage of the auction. This might have the advantage that the auctioneer would not necessarily need to cap the number of such bids and bidders could make use of any further information that they glean in the course of the open auction. Furthermore, it would only be necessary to enter this information in situations in which there would otherwise be unsold lots. However, to avoid undermining incentives for truthful bidding in the open auction, these last and final bids would still need to be capped at the level of prices in the relevant round where eligibility was dropped. This would seem to limit any benefit that could be achieved from delaying the best and final bids until the end. Also, entering best and final bids in the round when eligibility is dropped is an intuitively obvious process for bidders, whereas leaving all the best and final bids until the end would require complex data entry by bidders.

A2.23 If, at the end of the combinatorial clock stage, demand for each and every category of lots exactly equals supply, then a best and final offer stage is not required. The remaining bidders at the end of the combinatorial clock stage are allocated lots on the basis of their final bids in the combinatorial clock stage.

Best and final offers stage

A2.24 If there are unallocated lots in one or more categories at the end of the combinatorial clock stage, then a best and final offers stage is required. Those remaining bidders with eligibility to bid may make best and final offers on those packages on which they are still eligible to bid. There are no restrictions on the levels of these bids.

A2.25 Ofcom proposes to cap the total number of best and final offers that bidders with remaining eligibility to bid may make at 60 offers. The purpose of the cap is to simplify implementation of this part of the auction. Ofcom considers that the cap has been set at a sufficiently high level to ensure that bidders can adequately express their preferences for substitute packages of lots.

A2.26 Winning bids are then determined, taking into account all preferred package bids and all best and final offers submitted by all bidders during the combinatorial clock and best and final offer stages. The winning bids are the set of bids of greatest total value, subject to:

- no more lots being awarded than are available (i.e. no excess demand);
- at most one bid being accepted from each bidder.

A2.27 In the event that there is more that one set of bids of greatest total value, a random process shall be used to determine which set of bids is successful.

A2.28 Including in the winner determination all bids made during the first stage not only promotes an efficient outcome but should also encourage realistic bidding, as there is always a possibility that any bid submitted could be a winning bid. Further, because all package bids submitted by the same bidder are mutually exclusive, and are accepted or rejected in their entirety, bidders are not exposed to aggregation risks.

Determination of prices to be paid

A2.29 If the first stage is concluded without the need for a best and final offers stage, then winning bidders are committed to paying the amount of their winning bids in the combinatorial clock stage. This is called the ‘base price’ for a winning bid. (Additional payments in excess of the base price may be due if the winning bidder submits additional ‘top-up’ bids in the second stage to compete for specific frequencies.)

A2.30 In the case that a best and final offers stage is required, base prices are determined using a quasi-second price rule. These are prices paid for packages of lots by winning bidders such that:

- there is no dissatisfied bidder or grouping of bidders able to suggest an alternative outcome (in terms of prices paid and lots received by the bidder or group) preferred by all group members and which achieves at least as much total revenue;
- these are the lowest such prices, so there are not alternative prices satisfying the first condition which all bidders prefer; and

- revenue is at least as great as the outcome of the combinatorial clock auction.

A2.31 This corresponds to a notion of competitive pricing, in that winners have paid sufficient such that losers cannot suggest an alternative that does not make the seller worse off. Winners need to pay the minimum amount sufficient for there to be no other bidder or group of bidders willing to make a counter-offer for some or all lots that the seller would prefer.

A2.32 Typically, there are many possible prices satisfying these conditions. Among all these possible prices those closest to the combinatorial clock auction outcome would be selected.

A2.33 The advantage of this pricing rule over a simpler 'pay what you bid' rule is that it substantially reduces the incentives for the remaining bidders at the end of the combinatorial clock stage to shade their best and final offers, submitting bids significantly below their valuations. The amount that winning bidders will ultimately pay is determined primarily by the bids of competitors, so there are good incentives to make bids close to the value that bidders place on packages.

Transparency

A2.34 At the end of each round of the combinatorial clock stage the auctioneer will announce the level of excess demand for lots in each category. There are a number of further options for releasing additional information:

- releasing all preferred package bids on an anonymous basis (i.e. the packages bid on but not who made them);
- releasing all best and final offers on an anonymous basis; and
- full transparency of all bids made in the combinatorial clock auction (including the identity of the bidder).

A2.35 Ofcom considers that there is a case for, at least, releasing the details of all preferred package bids on an anonymous basis, as this should help reduce common value uncertainty. The pros and cons of additionally having full transparency are difficult to judge. Full transparency would provide somewhat richer information for bidders to benchmark their valuations against the behaviour of other bidders, and so further reduce common value uncertainty. However, much of this benefit would already have been obtained by releasing these bids on an anonymous basis. Against this, full transparency might facilitate collusive behaviour.

A2.36 Releasing information about best and final offers each round is potentially useful. Not only might this reduce common value uncertainty, but it also facilitates bidding by implicit consortia of smaller bidders who are trying to defeat other bidders who are aggregating lots. At the very least, it is useful to release the packages bid on in best and final offers on an anonymous basis. There is less reason to release the value of bids, as these can in any case be fairly closely inferred from the round prices. If bids amounts were released, it may be appropriate to round these off so as to prevent bidders using from using 'code bidding' to signal their intentions to other bidders.

Auction rules for the final assignment stage

A2.37 The final assignment stage is intended to turn the outcome of the first stage (in terms of the number of lots won by bidders) into an allocation of specific contiguous

frequencies within the four bands. Winners of the first stage participate in up to four parallel single round sealed bid auctions.

A2.38 This sealed-bid process allows bidders to pay a 'top-up' premium for specific frequencies over and above their 'base price' payment for generic lots as determined by the first stage. Bidders are guaranteed to receive an assignment compatible with the number of lots won in the first stage regardless of the amount of their top-up bids.

Four parallel sealed bids

A2.39 In the final assignment stage sealed bids are only required for categories of lots in which more than one bidder won lots in the first stage and where, therefore, the assignment of specific frequencies is uncertain. Thus there may be up to four parallel sealed bid processes, one each for Categories A, B, F and G. It is unnecessary to conduct a second stage sealed bid process for Categories C, D and E as there is only lot in each of these categories and therefore only one winner.

A2.40 All the sealed bid processes are conducted in parallel, i.e. the single round for each sealed bid takes place within the same bid window.

Commitments and feasible bids in the final assignment stage

A2.41 Winning a certain number of lots within a category in the first stage entails a commitment to accept any compatible package of specific frequencies in the final assignment stage. For example, if a bidder won three lots in Category A (10 GHz) in the first stage, this entails a commitment in the second stage to accept all available packages of three contiguous lots within the 10 GHz band.

A2.42 For each bidder in each of the sealed bid processes the auctioneer would first identify an exhaustive list of packages of contiguous frequencies which are consistent with the number of lots that it won in the first stage, and which would also allow all other winners to receive contiguous assignments. There will be a relatively small number of such packages of frequencies given the requirement for contiguity.

A2.43 Top-up bids in the second stage are limited to those packages of frequencies which are compatible with contiguous blocks being awarded. For example, suppose in the first stage that Bidder X won three lots and Bidder Y won seven lots in Category A (the 10 GHz band). In this case, Bidder X would be limited to bidding on either the top three blocks or the lowest three blocks by frequency, while Bidder Y would be limited to bidding on either the top seven blocks or the lowest seven blocks by frequency.

Making bids

A2.44 Bidders submit 'top-up' bids for packages of frequencies in each category that they are eligible to bid. The default bid for any available package of lots is zero. Bidders may submit higher bids for particular packages to express any preferences they might have for particular frequencies.

Winner determination

A2.45 The final outcome is achieved by optimising over the feasible assignments and finding the assignment with the greatest total value of accepted top-up bids, subject to allocating each frequency block to at most one bidder and accepting exactly one

bid from each bidder. Only combinations of winning bids that produce contiguous assignments will be considered.

Tie-breaking

A2.46 It is possible that many bidders may be indifferent about which package of contiguous frequencies they win within a band. Such bidders are likely to make the default zero top-up bids. As a result, it is possible that there may be more than one set of optimal assignments. In the event of ties, a random process would be used to pick one of the tied optimal allocations.

Payments

A2.47 Bidders pay the amount of their base price, as determined in the first stage, plus the amount of their successful top-up bids for each category in the second stage.

Publication of information

A2.48 Following the conclusion of the second stage, Ofcom plans to release full information about bids made throughout the auction and the bidders that made them.

Unsold lots

A2.49 If any lot remains unsold after the auction - either as a result of insufficient demand or default – Ofcom will review its approach to the release of the remaining spectrum and will choose whatever course it considers appropriate at the time.