26 GHz Award Auction Design

Prepared for ComReg

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DotEcon Ltd
17 Welbeck Street
London W1G 9XJ
www.dotecon.com

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Executive Summary

Re-award of national blocks

National block licences supporting point-to-point links in the 26 GHz band will expire in June 2018. Some initial steps towards possible future harmonization of this band for 5G use have been taken at the EU level. However, the timing of possible future developments is uncertain and it is likely that any future use for 5G will be able to coexist with point-to-point links to some degree. Therefore, notwithstanding these possible future developments, ComReg intends to re-award the expiring national block licences.

P2P, not PMP, with 19 blocks of 2x28 MHz available

The 2008 award process for 26 GHz national blocks awarded licences flexibly for either point-to-point (P2P) or point-to-multipoint (PMP) links. However, in the absence of any apparent demand for spectrum for PMP use, we recommend that only **P2P licences** are offered in this award. There would be **19 lots available**, each comprising 2x28 MHz of duplex spectrum.

Competition cap of 5 blocks

We recommend that a **competition cap** be set on the number of blocks that a single bidder can acquire in the auction. In the 2008 award, this cap was set at six blocks (with each block comprising 2x28 MHz). However, no bidder acquired more than five blocks in that award. Given this, we consider there is merit in a cap of **five blocks** for this award. This would allow at least four distinct winners, with the most concentrated possible outcome being three winners of five blocks and one winner of four blocks. We understand that at present the largest bandwidth on a single link that is useable with commodity equipment is 2x112 MHz (i.e. four blocks) and so a five-block cap does not appear unduly restrictive.

Sealed bid combinatorial auction

The **sealed bid combinatorial auction** used in 2008 remains fit for purpose. This comprised a single round of bidding for frequency-generic lots, with bidders able to submit multiple bids for different numbers of lots. Winning bids were selected to maximise the total value of winning bids subject to awarding no more lots than available. Prices paid by winners were determined on the basis of opportunity cost, using a second price rule (so-called minimum revenue core pricing). A follow-up stage determined the frequencies assigned to winners in line with the number of lots won in the initial stage.

Little reason for an open auction

We see no compelling need for use of a more complex and time-consuming open (multiple-round) auction process for this particular award, despite this methodology having been used in ComReg's recent spectrum awards. Unlike those awards, common value uncertainty is likely to be modest here given that winners may deploy national block licences in very different ways depending on the structure of their respective networks.

Options for the auction format

We recommend **two options** for the auction, depending on whether existing licensees are likely to have strong preferences across different frequency assignments due to the costs of retuning or replacement of equipment on existing links if assigned frequencies were to change.

Unless such frequency preferences are substantial, we recommend a sealed bid combinatorial auction using **frequency-generic lots** (**Option A**). This would determine the number of lots each bidder won. There would then be a follow-up frequency assignment process to determine which frequencies each bidder received.

Alternatively, if some bidders are likely to have strong preferences across frequencies (i.e. the value of a certain number of contiguous blocks depends strongly on which frequencies they are assigned), then we recommend a sealed bid combinatorial auction using similar rules, but with **frequency-specific lots (Option B**). Bids could only be made for contiguous ranges of (duplex) frequencies within the proposed competition cap. This significantly limits the number of options that a bidder could bid for, so this approach would not be unduly complex. With 19 blocks available and a cap of five blocks, there are 85 possible contiguous frequency ranges that could be subject to bids. This approach avoids the need for a follow-up process to assign frequencies.

Consultation to better inform choice between auction options

We recommend that ComReg consult on the extent to which incumbent licensees might face costs of moving frequencies that are material relative to the likely market value of this spectrum. This would better inform the choice between these two options for the auction design. However, the use of frequency-specific lots runs some risk of possible inefficient outcomes if either (i) bidders do not specify bids for all alternative frequency options they might be prepared to accept or (ii) bidders behave strategically, locating bids within the band to create fragmentation aimed at excluding other bidders. Whilst we consider these risks to be modest in practice, the use of frequency-generic lots is to be preferred unless there is a clear and compelling need to use frequency-specific lots.

Minimum price comprises the auction reserve price plus any annual spectrum usage fees

We recommend that ComReg set a **minimum price** for this auction to avoid frivolous participation and to discourage gaming behaviour aimed at reducing the prices paid. The minimum price represents the discounted stream of payments that any participant in the auction process can anticipate paying at minimum over the course of the licence; this comprises the lowest possible **spectrum access fee** (SAF) payable post-auction (i.e. the auction **reserve price**) plus any annual **spectrum usage fees** (SUFs) over the duration of the licence.

We recommend a minimum price of €245,000 per block

In determining the appropriate level of the minimum price, there are rather few comparable international benchmarks and a significant degree of uncertainty about estimates of market value of this spectrum. Although the 2008 award resulted in unassigned lots, it is reasonable to expect growth in demand for spectrum since then.

Uprating the 2008 minimum price in line with inflation would result in a minimum price of about €245k per 2x28 MHz block, which is below reasonable benchmarks for other competitive awards. Nevertheless, given uncertainty about the likely value of national blocks to bidders (which depends to a large degree on the alternatives available to bids for making backhaul network connections), we recommend that ComReg is cautious and does not increase the minimum price significantly above this level.

Recommended reserve price and SUFs

The minimum price can be implemented through a mix of SUFs and an auction reserve price. In general, the higher the auction reserve price, the lower the SUFs needed to achieve a given overall minimum price. In striking a reasonable balance, the auction reserve price should be sufficient to discourage frivolous bidding. However, the minimum price should not be implemented entirely through the reserve price, as SUFs have a useful role in creating incentives for spectrum that is not being used to be returned to ComReg.

We consider that a reasonable balance would be struck by setting an auction reserve price of €70k per 2x28MHz block together with 10 annual payments of SUFs over the life of licence of €25k per block (subject to annual indexation by CPI). This leads to an overall minimum price (i.e. discounted sum of reserve price and SUFs) of about €245k, which is very similar to the 2008 award. Roughly 30% of the minimum price would be recovered through the auction reserve price and about 70% through SUFs.

Licence conditions to permit P2P use

This is not award of options for 5G spectrum

In terms of licence conditions, it is important that this award process does not become distorted by bidders speculatively acquiring 26 GHz spectrum in the hope that incumbent national P2P block licensees might subsequently be able to use these blocks for 5G applications without paying the full opportunity cost of liberalised spectrum. Therefore, appropriate licence conditions should be set to allow technologically-neutral use for P2P links, but not broader PMP or mobile use. This will provide ComReg with flexibility to assign 5G usage rights at some future date once the policy environment is clearer, potentially in coexistence with P2P usage rights.

10-year licences

The previous 2008 award assigned licences for 10 years. Given the uncertain future for this band (and millimetre wave bands more generally) and the possibility of future harmonisation for 5G, there is good reason to keep the licences short. However, regard also needs to be given to the investment incentives of licensees. Therefore, we recommend that ComReg maintain a 10-year duration for these licences.

1 Introduction

DotEcon Limited has been commissioned by the Commission for Communications Regulation (ComReg) to consider the design of an award of 26GHz spectrum.

1.1 Spectrum available for award

26 GHz band and national block assignments

In 2008, ComReg awarded a number of **national block assignments** for deployment of fixed links in the 26 GHz band. These permit licensees to deploy fixed links at multiple locations throughout Ireland. These 10-year licences will expire in June 2018.

The 26 GHz band also contains a frequency range allocated for **individual link licences**. These provide an alternative route for deployment of point-to-point (P2P) links within the band. However, separate licences are issued by ComReg for each point-to-point link and each link is subject to an annual fee. Therefore, for operators deploying a large number of links, national block assignments may be preferred to multiple individual link licences for reasons of lower cost and greater flexibility. The 26 GHz band also contains licences used for fixed wireless access local area (FWALA).

5G use of 26 GHz

The 26 GHz band has been earmarked as a 5G pioneer band following an opinion from the EC Radio Spectrum Policy Group (RSPG), which recommended that at least part of the band be made available for 5G use by 2020. The EC subsequently issued a mandate to the CEPT to consider possible conditions for harmonised use of 5G in this band, with conclusions expected around the middle of 2018. Any harmonisation would need to be agreed by WRC-19, which implies that the end of 2019 is the earliest conceivable date by which any harmonisation measures could be enacted.

Therefore, existing national block licences will expire well before the earliest date by which any potential harmonisation of the 26 GHz band for 5G use might occur. Moreover, it is currently uncertain what part of the 26 GHz band might be used for 5G and whether this might coincide with that part of the band used for national block licensing. In any case, it is likely that there will be considerable potential for coexistence of fixed links with 5G use. Therefore, ComReg proposes to re-award the national block licences, even though there is a likelihood of some of the band being used for 5G in the future, possibly alongside fixed links.

Re-award of national blocks for P2P links

In 2008, national blocks were offered optionally for either point-to-point (P2P) or point-to-multipoint (PMP) use. However, those few blocks that were awarded for PMP use have either been returned to ComReg or converted to P2P use. There is currently no evidence of demand for future PMP use. Therefore, this report concentrates on potential auction designs for re-award of the national blocks for P2P use only.

Use of the 2008 guard block

There are no implications of this award for the frequency ranges in the band currently used for FWALA and individual link licences. However, it is proposed that a guard block left between the national block and FWALA assignments in the 2008 award is made available as a national block. As a result, there will 19 duplex blocks of 2x28 MHz available.

1.2 Objectives for the award

ComReg's objectives

ComReg's functions include the management of Ireland's radio frequency spectrum. This is conducted in accordance with ministerial Policy Directions under the 2002 Communications Regulation Act and having regard to its objectives set out in the Framework Regulations and Article 8(a) of the Framework Directive. In line with ComReg's statutory objectives, a key aim for the award of any spectrum rights is to achieve an efficient allocation and to ensure that the spectrum is subsequently used efficiently. Any award should also meet ComReg's overarching objectives of promoting competition, encouraging development of the internal market and protecting the interests of consumers.[1]

In line with the Framework Directive, ComReg is required to grant licences using selection criteria that are objective, transparent, non-discriminatory and proportionate. Where a competitive procedure is to be used, ComReg is required, under the Authorisation Directive, to ensure that such a procedure is fair, reasonable, open and transparent to all interested parties.

Use of auctions

In its most recent Spectrum Strategy Statement[2], ComReg outlined its current thinking on the advantages of certain award mechanisms, including auctions.[3] It reiterates ComReg's previously held position of not necessarily favouring any specific approach for awarding spectrum rights of use, preferring to consider each award on its merits. Nevertheless, the Statement acknowledges that auctions

[1] Communications Regulation Act, 2002 as amended.

[2] ComReg, 'Radio Spectrum Management Strategy 2016-2018', ComReg 16/50, 21 June 2016

[3] Section 7.1 of ComReg 16/50

offer clear potential benefits. We propose the use of an auction for this award given the strong possibility that the available spectrum could be oversubscribed.

Where auctions are to be used, ComReg does not favour any particular auction format, but rather believes that formats should be assessed based on the specific circumstances of each award. We consider that a similar approach to that used in 2008 – a sealed bid combinatorial auction – is appropriate, but somewhat simplified in that licences would only be offered for P2P use, not PMP. We see no compelling need for the use of an open auction given the particular circumstances applying to this band.

We present two variations of this auction design, depending on whether frequency-generic lots (Option A) or frequency-specific lots (Option B) are used. The 2008 award used frequency-generic lots with a follow-up assignment process to determine the specific frequencies awarded to winners. It is possible that an auction with frequency-specific lots might be more appropriate if incumbent licensees face significant costs of retuning frequencies that need to be reflected in their bids. However, there is also some risk of inefficient outcomes associated with the use of frequency-specific lots. These risks are largely theoretical in nature, but nevertheless suggest using frequency-generic lots unless there is a demonstrated need for using frequency-specific lots.

Competition issues

An award process can often achieve an economically efficient outcome by assigning spectrum to the users with greatest value for it. However, in certain circumstances it may be appropriate to adopt provisions to avoid excessive concentration of spectrum holdings if this could weaken competition in the downstream markets; in such a case valuations for spectrum would in part reflect the maintenance or extension of market power. Although competition issues are not of central importance in this award, we propose a cap on the number of national blocks that any one bidder can acquire. We consider that a cap in the range of four to six blocks would be appropriate, with a cap of five blocks having the advantage of ensuring reasonably unconcentrated outcomes, yet also not unduly restricting licensees' deployment plans.

1.3 Structure of this report

The remainder of this report is organised as follows:

- In section 2, we set out the background to the award, how the spectrum might be used and the current market situation. We also briefly summarise the structure and outcome of the 2008 award;

- In section 3, we discuss the question of whether there should be a competition cap on the number of blocks that can be acquired by any one bidder;
- In section 4, we briefly discuss other (non-technical) aspects of licence conditions, including the licence duration;
- Section 5 forms the centrepiece of the report – a consideration of options for the award design. We recommend that ComReg use a similar approach to the 2008 award – a sealed bid combinatorial auction. We also discuss the setting of a minimum price for national blocks and how this should be split between an up-front charge and continued annual fees;
- Section 6 provides a brief summary of our recommendations.

There are also four annexes:

- Annex A summarises the charges currently in force for licensing of individual links;
- Annex B discusses bidding incentives in second price auctions through the use of some simple examples;
- Annex C lists recent awards of broadly comparable spectrum in other jurisdictions;
- Annex D provides two worked examples showing the operation of the two options for the auction design.

2 Background

This section discusses the background to the award, including the previous auction of 2.6 GHz national block licences run by ComReg in 2008, current use of the band and potential future use.

2.1 Current market situation

Primary and secondary uses

The 26 GHz band (24.45-27 GHz) is currently licenced (and used) in Ireland for a mix of:

- **Fixed point-to-point (P2P) links licensed on an individual link basis** in accordance with Statutory Instrument 370 of 2009 ('individual link assignments');
- **Fixed P2P links using spectrum blocks licenced on a national basis** in 2008 in accordance with Statutory Instrument 762 of 2007 ('national block assignments'); and
- **Fixed Wireless Access Local Area (FWALA) licences for point-to-multipoint use.**

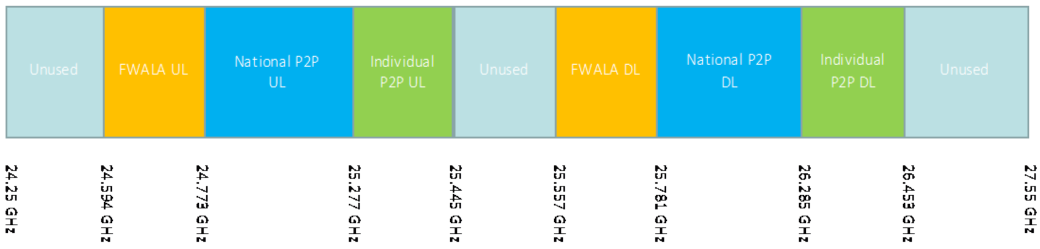
Use of the band is also permitted on a secondary basis for automotive short-range radar (21.65–26.65 GHz) and industrial probing radar (24.65–25.5 GHz).

The overall arrangement of the band of the various primary services is shown in Figure 1 below. The national P2P blocks allow licensees to deploy point-to-point links as they choose (within the terms of the licence) without further need for a licence from ComReg. In contrast, in the individual P2P blocks it is necessary for those deploying point-to-point links to obtain a licence from ComReg for each specific P2P link. Therefore, the national block licences provide significant additional flexibility for operators deploying multiple P2P links.

A further key difference between the two licensing routes is that it is only possible to obtain contiguous bandwidth of up to 2x28 MHz under an individual link licence; whilst spectrum for multiple links can be sought, these might not be at adjacent frequencies given the process for allocating available channels for links. In contrast, national block licensees can deploy links with bandwidth limited only by the number of (contiguous) national blocks held.

For operators deploying a sufficiently large number of fixed links, national blocks will be cheaper than multiple individual link licences. At the prices for national blocks set in 2008 award, the breakeven point is around 40 links, though the precise number depends on the bandwidth of individual links. Annex A discusses the current charges for individually licensed P2P links.

Figure 1: Overall band plan



The 2008 auction and current assignment of national blocks

The national block assignments were awarded in 2008 using a second price sealed bid combinatorial auction (whose format and rules are discussed in detail in the following subsection). The auction resulted in 13 of the 17 available 2x28 MHz national blocks[4] being assigned to five different bidders, three of which were for PMP use with the remainder for P2P. Subsequently:

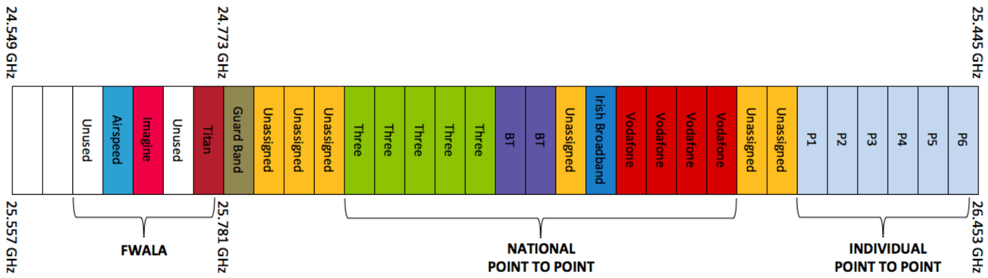
- Digiweb Limited surrendered its single PMP block in 2009; and
- Three (then Telefonica) changed the two PMP block licences it was awarded into P2P blocks (giving it a total of five P2P blocks) in 2012.

Therefore, there are currently twelve 2x28 MHz national block assignments for P2P use, split across four operators. The current duplex assignment is shown in Figure 2 below. There are six blocks currently unassigned (shown in yellow); these are scattered across the band and do not form a contiguous duplex block.

There is also a guard block separating the lower end of the national block frequency range from FWALA licences. We understand that ComReg intends this block be made available as a national P2P block in the current award. Current FWALA licences are geographically limited and there is limited scope for interference between FWALA licensees and an adjacent national block user. Therefore, there will be 19 duplex blocks of 2x28 MHz available in this award.

[4] A total of 18 2x28 MHz blocks were available in 2008, but the highest frequency block would have been designated a guard band in the event that all other lots were assigned.

Figure 2: Detailed assignment



Backhaul is the main use

Point-to-point links are primarily used for providing backhaul services for mobile networks (i.e. to connect a mobile base station to the core network) as well as providing backhaul connectivity for fixed wireless access networks and general backbone network capacity for telecoms providers competing with the incumbent fixed operator, Eir.

Users of national block assignments

There are currently three main mobile network operators in Ireland:

- Vodafone Ireland is the largest operator with approximately 37% share of subscribers (as of March 2017[5]);
- Three Ireland has a market share of around 33% of subscribers, following its merger with O2 Ireland in March 2015; and
- Meteor, which is owned by the incumbent fixed line operator Eir, has a market share of approximately 20% of subscribers.

Vodafone has four of the current national block assignments in the 26 GHz band and operates 2,348 fixed point-to-point sites[6] using this spectrum (as of May 2017). Additionally, Vodafone has 39 individual link assignments. Three has five of the national block assignments in the band and operates 3,092 point-to-point sites. Three also has 149 additional links assigned in the individual point-to-point link spectrum. Meteor does not hold any national block assignments but holds 215 individual link assignments. Eircom holds a further four individual link assignments. BT holds two of the national block assignments and has 15 sites. Irish Broadband has one of the national block assignments and operates 74 sites.

Other organisations using fixed links

Other organisations holding individual link assignments are (as of May 2017):

- Virgin Media (four links);

[5] See ComReg 17/50.

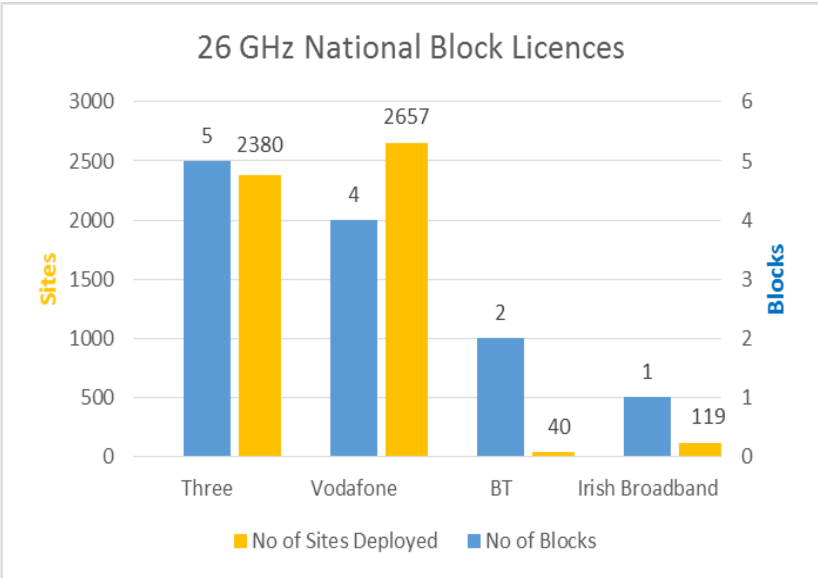
[6] Data on P2P links provided by ComReg; figures relate to May 2017.

- Airfibre (two links);
- ESB (two links); and
- Dundrum Credit Union (one link).

Numbers of deployed P2P links

The current number (as of September 2017) of fixed links deployed in the national blocks is summarised in Figure 3 below. There are around 5,200 P2P sites in total. A link is between two sites; it is possible that a site could be the endpoint of more than one link, though we understand this situation occurs infrequently. Therefore, there are roughly 2,600 links in total deployed in the national blocks.

Figure 3: Fixed P2P deployment in national blocks



(Source: ComReg Data for September 2017)

In addition, P2P links are deployed under individual link licences, operating within the six 2x28 MHz blocks at the top of the band. There are 384 individual P2P links licenced in this manner (as of September 2017), compared with about 2,600 links deployed within the national blocks. Therefore, national blocks have in practice provided the main route for P2P link deployment ion the 26 GHz band, but use of individually licenced links remains significant.

Potential demand growth for P2P links

Demand for spectrum for fixed links is likely to increase in the future as bandwidth requirements on both fixed and mobile networks increase.[7] In particular, the growth in mobile data traffic levels on an individual base station site of a mobile operator (due to more spectrally efficient technologies such as LTE being deployed and additional frequency bands becoming available for use at each site) is projected to multiply many times over the coming decade. Additionally, the number of sites deployed could increase significantly as operators look to move to a denser small cell architecture in more populated areas. Whilst fibre links are likely to be key for much of the backhaul connectivity, especially in urban areas, in practice microwave links are still anticipated to continue to play a key role for providing backhaul connectivity in view of their cost advantage and speed of deployment (particularly in locations where an existing fibre connection is not available, especially rural areas).

Other bands for fixed links

The 26 GHz band forms one of 22 different spectrum bands available for licensing for individual point-to-point links. The main bands (in terms of numbers of individual link assignments) are the 38 GHz, 23 GHz, 15 GHz, 13 GHz, 18 GHz and 11 GHz bands.

These other millimetre wave bands provide potential alternatives to the 26 GHz band for fixed links. Higher frequencies may be useful for links with greater bandwidth, though these will also tend to have shorter propagation and may be more affected by atmospheric conditions.

FWALA deployment in 26 GHz

Five channels within the 26 GHz band are currently set aside for FWALA licences. These are 12 month rolling licences for 28 MHz blocks, and provide rights of use for a specific channel within a local area defined by:

- a geographic coordinate (specified by the licensee upon application); and
- a radius of 20km around that coordinate (with an interference radius of 30km).

There are very few FWALA licences currently issued in the 26 GHz band and these apply into just two geographical areas:

- Airspeed Communications Ltd has one licence in Dublin in channel B;
- Imagine Wireless Ltd has one licence in Dublin in channel C; and

[7] We note, for example, that ComReg's spectrum strategy for 2016-18 references studies indicating that mobile data traffic is expected to grow by a factor of 15 between 2015 and 2025.

- Titan Consultancy Limited has one licence in Limerick in channel E (immediately below the current guard block)

ComReg considers that there is no longer any concern over interference issues between FWALA and P2P users, hence the current guard block can be included in the auction. If participants in the auction consider that they have a particular need for a guard block, this should be factored into their bids.

2.2 Potential future use of 26 GHz for 5G

In November 2016, the Radio Spectrum Policy Group (RSPG) identified the 24.25-27.5 GHz band as one of the 5G pioneer bands.[8] The 3400-3800 MHz and 700 MHz bands were the other two bands identified for an early implementation of 5G in Europe.

Within the millimetre wave bands, the RSPG focused its analysis on the bands proposed by European countries at WRC-15 (i.e. the 24.25-27.5 GHz, 31.8-33.4 GHz and 40.5-43.5 GHz bands). Although all these bands were recognised by RSPG as having potential interest for the deployment of 5G in Europe, the 26 GHz band was denoted as the most appropriate for the deployment of 5G by 2020. According to the RSPG, the decision was based on the mobile industry support for the band.

In its opinion[9], the RSPG considered that there was a need for the harmonisation of the 26 GHz band and that Member States should make at least a portion of the band available before 2020. It also indicated that a timeline for the availability of other millimetre wave bands in the EU would be announced at a later stage.

5G bands in non-European countries

In July 2016, the US identified the 27.5-28.35 GHz, 37-40 GHz and 64-71GHz bands for the deployment of 5G[10]. Korea is planning to use the 25.6-29.5GHz band for 5G trials in 2018 and trials in Japan are planned from 2017 in the 27.7-28.28 GHz band[11].

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[8] Radio Spectrum Policy Group, 9 November 2016, *Strategic Roadmap towards 5G in Europe – Opinion on spectrum related aspects for next-generation wireless systems (5G)*, Brussels, available at http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

[9] *Ibid*

[10] FCC, 14 July 2016, Press Release '*FCC takes steps to facilitate mobile broadband and next generation wireless technologies in spectrum above 24 GHz - New rules will enable rapid development and deployment of next generation 5G technologies and services*', available at https://apps.fcc.gov/edocs_public/attachmatch/DOC-340301A1.pdf

[11] https://gsacom.com/5g-spectrum-bands/

Following the RSPG opinion, the European Commission issued a mandate to the CEPT to '*develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union*' in the identified pioneer bands[12]. The mandate is to be completed during the first half of 2018. Therefore, there is likely to be little certainty about potential future harmonisation with the 26 GHz band prior to the expiry of the current national block licences.

mmWave bands under study

In line with the EC mandate, CEPT is currently conducting studies for the introduction of 5G in the 26 GHz band taking into account the protection of all existing services in the band and in adjacent bands. Different sharing scenarios including fixed links, earth exploration satellite and space research services, fixed satellite services, data relay satellite systems and passive services will be considered by these studies.

Additionally, compatibility and sharing studies are also being conducted at ITU-R level in the millimetre wave bands that were identified by WRC-15[13]:

- 24.25-27.5 GHz;
- 31.8-33.4 GHz;
- 37-43.5 GHz;
- 45.5-50.2 GHz;
- 50.4-52.6 GHz;
- 66-76 GHz and
- 81-86 GHz.

Based on the results of the studies, WRC-19 will decide on possible additional allocations to the mobile service, on a primary basis, for 5G deployment. Although CEPT supports the development of studies on all the bands identified by WRC-15, a questionnaire was launched on the need to prioritise some of them in terms of the studies to be conducted prior to 2019. The questionnaire was answered by 41 stakeholders, including national regulatory

[12] European Commission, RSCOM16-40, 7 December 2016, *Mandate to CEPT to harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union*, Brussels, available at https://circabc.europa.eu/sd/a/2c305fdf-4265-44bf-95d2-b84a13a267d4/RSCOM16-40%205G%20draft_mandate_CEPT.pdf

[13] ITU-R, 2015, *Resolution 238 (WRC-15), Studies on frequency-related matters for International Mobile Telecommunications identification including possible additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of International Mobile Telecommunications for 2020 and beyond*, Geneva, available at https://www.itu.int/dms_pub/itu-r/oth/oc/oa/R0C0A00000C0014PDFE.pdf

authorities, associations and industry, but there is little consensus so far:

> *'Many respondents were of the view that the bands below 43.5 GHz (i.e. 24.25-27.5 GHz, 31.8-33.4 GHz and 40.5-43.5 GHz) should be prioritised for early studies, whereas others believe that no prioritisation of bands for study is necessary at the early stage band for studies'*[14].

Final remarks

Although the 26 GHz band was identified as a pioneer band by the RSPG for the deployment of 5G in Europe by 2020, it is not the case that this would preclude future use of the band for fixed links either in the short or medium term:

- studies are currently being developed and will define the technical conditions for the use of the band, including the channelling arrangement and the potential for coexistence with other users, including fixed links;
- WRC-19 will decide on the allocation of the band - or parts of it - to the mobile service on a primary basis for the development of 5G, which means that no final decision in terms of Radio Regulations will be taken before 22 November 2019 (by which time current national block licences in the 26 GHz band will have expired);
- compatibility and sharing studies, as well as developments in other non-European countries, might reveal that other millimetre wave bands are superior to the 26 GHz band for initial deployment of 5G.

Approach to future risks associated with 5G

Given the importance of P2P links to operators' networks at present, the impending expiry of national block licences, uncertainty about when this band might be used for 5G applications and the possibility of harmonious coexistence of 5G with existing P2P links, we understand that ComReg's preference is to re-award national block licences in their current form. However, at the same time, we acknowledge that there is potential that the identification of 26 GHz as a 'pioneer band' for 5G presents some risk to licensees that the terms of licences could need to be changed at a subsequent date or, in the worse conceivable case, curtailed to some degree.

At present, it is not possible to identify these risks with any clarity. CEPT is commencing research to consider the potential for co-existence of 5G applications with incumbent users in millimetre wave bands, though it will be some time until findings are published. Nevertheless, at least in principle, there should be considerable potential for co-existence between P2P links and 5G applications, including the 'Internet of Things'. Therefore, these risks to national

[14] https://www.cept.org/ecc/topics/spectrum-for-wireless-broadband-5g

block licensees need to be acknowledged, but should not be overemphasised. Given this situation, we have adopted the approach in this report of considering auction design for re-award of national block licences without any specific provisions related to possible future 5G use.

Option for future 5G use and potential for a distorted award

It is important that the current award does not become a surrogate auction of spectrum for potential 5G future use. If some bidders considered that they were acquiring an option to use 26 GHz for 5G applications in the future (especially if at a price below the likely market value of liberalised spectrum permitting 5G use), there is a risk of a distorted and inefficient award. Bidders could have diverse views about what potential there might be to migrate spectrum to 5G use. This could result in an outcome for the proposed award that was significantly affected by some bidders' views about the potential for existing licensees to change the licence terms of national P2P blocks to allow 5G use. This could be unfair to potential P2P users, if they were precluded from access to spectrum due to speculative bidding on the basis of acquiring future leverage over access to 5G spectrum. Equally this could also be unfair to potential future 5G spectrum users who might find themselves excluded from this spectrum in some point in the future due to claims of incumbent users.

To avoid these problems, we recommend that ComReg set licence conditions that provide a high degree of regulatory certainty that national blocks cannot be used at a future time for 5G deployment. We consider such licence conditions in Section 4. This would then provide a clear position for future award of 5G usage rights (in the light of the findings of coexistence studies) if there is eventually harmonisation of some of the band for 5G use. This proposed approach would leave ComReg with a range of future options for meeting any 5G harmonisation obligation without unfairly favouring existing P2P national block licensee in the band, including:

- the possibility of issuing 5G usage rights as an overlay in parallel with existing P2P usage;
- the possibility of providing an option for P2P licensees to liberalise licences to allow other uses (including 5G), but at an appropriate market-determined price (similar to the early liberalisation options provided in the MBSA award).

2.3 The 2008 award of national blocks

The spectrum rights of use in the 26 GHz band were previously awarded in 2008 using a sealed bid auction. This was a combinatorial auction using a second price rule (which we explain in detail in Section 5).

Outline of the 2008 auction

Its key features were that:

- The available 2x504 MHz of spectrum was split into 18 blocks of 2x28 MHz, with the highest frequency block designated a guard band in the case that all other blocks were assigned (hence there was maximum of 17 blocks available to bidders);
- The available blocks could be used either for P2P or PMP;
- ComReg did not assign specific frequencies for particular use, but blocks assigned for P2P were to be located at the top of the band and PMP blocks at the bottom;
- If a combination of P2P and PMP blocks were assigned, one of the other blocks would need to be a designated guard band in between the P2P and PMP users;
- A competition cap was applied to protect downstream competition, preventing bidders from acquiring more than six lots;
- In a qualification stage, bidders submitted their application bids, specifying the number of P2P blocks and the number of PMP blocks they desired at reserve prices.
- If there was excess demand for the blocks based on the application bids (and taking into account the need for guard bands), the award would proceed to a sealed bid stage, in which bidders could submit a number of exclusive bids for different packages of generic P2P and/or PMP blocks; the competition cap meant that a bidder could bid for a maximum of 27 unique packages. Winners and prices would be established on the basis of selecting the feasible assignment of lots yielding the maximum total value of bids (subject to each bidder winning at most one of the packages it bid for), and the application of a second price rule;
- If there was no excess demand based on application bids, bidders would win the package specified in their application bid and pay the reserve price for the package. The reserve price was €70,000 per 2x28 MHz block, but winners could also anticipate paying annual spectrum usage fees (SUFs) of €20,000 per block in years 2 to 4 (inclusive) of the licence and €40,000 per block annually for the remainder of the licence.
- Winning bidders could then place additional bids (in a second sealed bid process) for specific frequency assignments, based on the number of lots it won, the requirements that winners were awarded contiguous blocks (for a given use), and in line with the rules for separating the P2P and PMP users.

Outcome of the 2008 auction

The award process ultimately did not require the sealed bid stage as it was possible to accommodate the demand specified in the application stage with the blocks available. 13 blocks were assigned to five different bidders; 10 of the national block assignments were for P2P use, and three were for PMP, as shown below.

Table 1: Irish 2008 26 GHz Award Outcome

Winning Bidder	Number of P2P lots	Number of PMP lots
Vodafone	4	0
Three	3	2
BT	2	0
Irish Broadband	1	0
Digiweb	0	1

One of the PMP licences was subsequently returned (by Digiweb), and the other two were subsequently converted to P2P in 2012 by Three.

2.4 Spectrum available for award and potential demand

The spectrum available in this award consists of the same blocks as made available for P2P and PMP use in 2008. However, the guard band between FWALA and P2P blocks can be made available for P2P use given that the adjacent FWALA block is only being used in two regions[15]. We understand that, as a result, ComReg considers that there is limited risk of interference.

Blocks available

The use of these frequencies for P2P links requires blocks sizes of 2x28 MHz to be maintained. Therefore, there will 19 national blocks available with frequencies as set out in Table 2 below.

[15] Airspeed and Imagine each have one FWALA licence in Dublin (in channels B and C respectively), and Titan has one FWALA licence in Limerick in channel E.

Table 2: Duplex frequencies by block

Block	Lower frequencies (GHz)	Upper frequencies (GHz)
A1	24.745 – 24.773	25.753 – 25.781
A2	24.773 – 24.801	25.781 – 25.809
A3	24.801 – 24.829	25.809 – 25.837
A4	24.829 – 24.857	25.837 – 25.865
A5	24.857 – 24.885	25.865 – 25.893
A6	24.885 – 24.913	25.893 – 25.921
A7	24.913 – 24.941	25.921 – 25.949
A8	24.941 – 24.969	25.949 – 25.977
A9	24.969 – 24.997	25.977 – 26.005
A10	24.997 – 25.025	26.005 – 26.033
A11	25.025 – 25.053	26.033 – 26.061
A12	25.053 – 25.081	26.061 – 26.089
A13	25.081 – 25.109	26.089 – 26.117
A14	25.109 – 25.137	26.117 – 26.145
A15	25.137 – 25.165	26.145 – 26.173
A16	25.165 – 25.193	26.173 – 26.201
A17	25.193 – 25.221	26.201 – 26.229
A18	25.221 – 25.249	26.229 – 26.257
A19	25.249 – 25.277	26.257 – 26.285

P2P vs PMP use

The current pattern of use suggests that demand for these blocks is likely to be for P2P use rather than PMP use, in that blocks awarded for PMP use in 2008 have been subsequently returned or converted in P2P use. Therefore, unless there is credible evidence of demand for spectrum for PMP applications at consultation, we would recommend that this award only make blocks available for P2P use.

This approach of limiting use to P2P has a number of incidental benefits. First, it means that the complications arising in the 2008 auction from use of a variable band plan determined within the auction itself can be avoided. Second, use of this spectrum for P2P links is likely to be more compatible with future co-existence with 5G applications than it would be with PMP use.

Demand for P2P national blocks

Despite the 2008 auction having unassigned blocks, we would expect strong demand for national P2P blocks. Existing licensees are likely to have significant value in retaining national block allocations. In addition, there may be interest from Meteor/eir for national blocks in place of or in additional to the individual licences it holds.

The bandwidth available on a particular P2P link is a function of the number of contiguous blocks of spectrum being used. Given growth in demand for bandwidth since 2008 and likely future trends, it is possible that existing licensees could want a greater number of blocks.

All these factors suggest that excess demand for the 19 available blocks is probable and that an auction process will be required to resolve excess demand. Clearly if there were no excess demand, then blocks would simply be assigned at reserve prices, as in the 2008 process.

3 Competition caps

In recent spectrum auctions, ComReg has set a cap on the amount of spectrum that can be acquired *in the auction* to protect competition in downstream markets. Such caps are not long-run constraints on the amount of spectrum an operator may hold, as the competition impact of any spectrum transaction would need to be considered in the light of market conditions at the time it was notified to ComReg.

The 2008 auction cap of six blocks

Cap in the 2008 award

In the 2008 award, there was a cap of six 2x28 MHz blocks. Such a cap means that there would be at least three winners (given sufficient demand) given 18 blocks available in that auction. However, the largest amount of spectrum won by any bidder was five blocks (by Three).

Therefore, it would appear that, at least to date, there has not been any demand expressed for six adjacent blocks, despite the competition cap being set at this level in 2008.

Risk of anticompetitive bidding motives

Overall, even if there were no competition cap, there is no strong reason to expect there to be an anticompetitive motive for a bidder to acquire spectrum to limit the number of winners of national P2P blocks, particularly in the short run.

Alternatives to 26 GHz national blocks

There is likely to be a limited impact on downstream markets, as the option of using individual licences would remain open (as has already been used by Meteor to date). In addition, there are options to use other spectrum bands for P2P links and to make greater use of fibre links. However, as shown in Annex A, as the number of links an operator is using grows, national blocks are likely to become more cost effective at some point (depending on the price of those national blocks).

Hoarding for 5G

Even though licences will be initially assigned for P2P only, there may be a small risk of operators attempting to acquire more spectrum than needed for P2P in the anticipation of getting a head start over competitors in the event of early liberalisation of the licences to allow for 5G. Whilst this is likely to be a risky strategy, given the uncertainty over the introduction of 5G and any terms ComReg might apply along with early liberalisation to protect competition, there might be some merit in pre-empting such behaviour.

Therefore, we consider it prudent to impose a safeguard cap on the amount of spectrum that can be acquired in the award to prevent a single winner gaining so much spectrum that it would be in a highly asymmetric position relative to other winners. However, we do not see a strong need for setting a tight auction cap to allow for many winners (say at less than 4 blocks). In addition, there is a danger of excluding users with larger bandwidth requirements, as there are examples of fixed links with four blocks in use. Therefore, the auction cap only needs to have a limited role in safeguarding against excessively concentrated outcomes.

Proposed five-block competition cap

Cap in the range of 4-6 blocks

Given the lack of any deployment of links using six national blocks, it would appear feasible to reduce the six-block cap used in 2008 to five or even four blocks without significantly constraining operators.

A cap at a lower level would have the following effects:

- A cap of four blocks would allow for five winners (though at least one would receive three blocks or less) given sufficient demand;
- A cap of five blocks would allow for four winners (though at least one would receive four blocks or less) given sufficient demand.

A five-block cap has the attraction of providing opportunity for at least four winners each to gain at least four blocks, which would be sufficient to meet the very large majority of current usage patterns on fixed links. For example, it would allow the existing three mobile operators and one additional operator to all win at least 4 blocks each. It is unlikely that there would be significant benefit from reducing the cap further to 4 blocks, and there would be some risk of constraining demand from bidders given that Three already has five blocks from the 2008 award.

For these reasons, we recommend a competition cap set at five blocks. We understand that at present the largest bandwidth on a single link that is useable with commodity equipment is 2x112 MHz (i.e. four blocks) and so a five-block cap does not appear unduly restrictive.

4 Licence conditions

4.1 Licence duration

Licences in the 2008 award had a duration of 10 years. ComReg has issued longer duration licences in recent spectrum awards (such as the 3.6GHz award and the MBSA). However, the particular circumstances of this award suggest maintaining a duration of ten years. In particular, if a requirement to make part of the 26 GHz band available for 5G emerges at some future date, there may be some risk of needing to modify existing licences to meet obligations to make harmonised spectrum available for 5G use. Whilst there are likely to be opportunities for coexistence of P2P links with 5G use and these risks should not be overstated, clearly making P2P national block licences longer increases the exposure of licensees to such risks. It would also push back ComReg's ability to reconfigure the band further into the future. Therefore, we would not recommend that ComReg set a longer duration for these licences given current uncertainty about future developments for the band.

Equally, whilst such uncertainty might even provide an argument for shortening the licence duration, a 10-year duration is already relatively short compared with other spectrum licences issued by ComReg and by comparison with international practice. Shortening the duration further (say to less than 8 years) could run significant risks of making complementary investments in equipment unattractive for operators, particularly during the latter part of the licence life.

Given these competing considerations, we would recommend maintaining a 10-year duration.

4.2 Usage restrictions

We have already set out in Section 2.2 why we consider it to be important that P2P national block licences do not provide a backdoor route to 5G deployment at some future date. Therefore, we recommend that ComReg require that these licences be used to provide P2P links, rather than mobile services or PMP links to connect end-customers. This would also simplify any future requirement for coordination with 5G use if that were to arise subsequently.

Subject to this usage restriction and reasonable restrictions to prevent interference with adjacent licensees, licences can be technology neutral.

4.3 Structure of spectrum fees

Minimum price in 2008

The fees for national block licences set in 2008 amounted to a total (on an undiscounted basis[16]) of about €350k per 2 x 28 MHz lot, split into:

- A spectrum access fee (SAF) initially payable of €70k per 2x28 MHz lot (which was the price determined by the auction, as there was no excess demand); and
- A spectrum usage fee (SUF) of €280k paid in nine annual instalments (€20k for years 2-5, €40k for years 6-10), adjusted for CPI.

Using a discount rate of 9%, the present value of the fees for a 2x28 MHz national block is about €245k in 2008 terms. [17] There has been little overall price inflation since 2008 due to the period of deflation from mid-2008 to 2010;[18] therefore, we do not need to make any significant correction for inflation. Roughly a quarter of the total minimum price set in the 2008 (i.e. the reserve price for the auction plus ongoing annual spectrum usage fees) was recovered through the SAF, with the remainder deferred into annual SUF.

Need for a minimum price

There are good reasons for setting minimum prices. Minimum prices reduce incentives for strategic behaviour within an auction aimed at decreasing the price paid. This includes both tacit collusion within an auction and also arrangements entered into prior to an auction aimed at decreasing competition within the subsequent auction. Therefore, we strongly recommend that ComReg maintain a minimum price for this award, not least to discourage frivolous bidding.

Balance between annual fees and reserve price

The minimum price comprises both the minimum possible SAF (set by the reserve price for the auction) payable soon after completion of the award and ongoing annual SUFs (indexed by inflation) that licensees can anticipate paying. In terms of how a minimum price might be split between an initial SAF and annual SUFs there is typically a balance of considerations:

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[16] Please note that the documentation for the 2008 auction, including the information memorandum, generally refers to the undiscounted total payments and so a minimum price of €350k per block. However, in this report we will use discounted sums of payments for assessing the minimum price and structure of fees.

[17] The exact discount rate used is not critical for our assessment of the minimum price given other uncertainties. ComReg's current estimate of a typical mobile WACCs is 8.63% (nominal and pre-tax). See ComReg 14/136. By rounding up, we reduce the estimated benchmarks.

[18] See https://data.oecd.org/chart/4Toy

- ensuring that a reasonable part of the overall price of spectrum determined by the auction is recovered through a payment made soon after the payment discourages speculative bids that might not be firmly financed;
- on-going usage fees face licensees with an actual cost (as opposed to just an opportunity cost) that encourages return of unused spectrum to ComReg.

These competing considerations still apply in this award and a similar approach can be maintained as in the 2008 award. We do not consider the choice of the split of the minimum price between the reserve price (i.e. the minimum SAF) and annual SUFs is critical to the success of the award.

We see no particular reason for providing a discount to SUFs for the early years of the licence (as was used in the 2008 award) in preference to the simpler approach of setting a fixed SUF that is then uprated with inflation (i.e. constant in real terms).

4.4 Level of spectrum fees

In this subsection, we first estimate the likely market value of 26 GHz spectrum based on comparable international awards. We then consider how these estimates are related to the likely value of national blocks within the broader context of licensing for P2P links.

As discussed above, the total minimum price (auction reserve plus annual fees) was roughly €245k per block (on a discounted basis) in the 2008 auction. Although not all blocks were assigned in that award, there is reason to expect demand for 26 GHz spectrum for P2P links to have grown over the last decade.

4.4.1 Benchmarking results

In order to estimate the value of spectrum, we are mostly interested in competitive auctions where competition determined the ultimate winners and the prices paid. In uncompetitive auctions, lots would be allocated at reserve prices and the results would therefore only represent a lower bound on true opportunity costs. While reserve prices could have been set to reflect estimates of market value, it is unlikely to capture the full market value as a prudent regulator would typically recognise the uncertainty over the value estimates and set conservative reserve prices to avoid "choking off" demand.

To compare spectrum licence prices across different jurisdictions, we adjust prices to a common basis. We express licence prices in 2017 Irish prices per MHz per capita by making adjustments for award-specific factors, such as the duration of the licence, the amount of spectrum sold, and the population covered by each licence:

- *Stream of payments:* We calculate the present value of the stream of payments that the licence holder makes over the licence duration (for example, the licensee may pay an upfront headline price and then annual administrative fees, or the headline price may be paid in instalments). We use a discount rate of 9% (as used throughout for discounting payment streams).
- *Licence duration*: We normalise licence prices to a common licence term of 10 years. This adjustment is based upon the assumption that licences have a constant payoff over their duration.
- *Currency differences*: We convert licence prices to a common base currency using Purchasing Power Parity (PPP) exchange rates, and express in 2017 prices using the United States Consumer Price Index. PPP exchange rates are used over market exchange rates because we are in interested in comparing real prices across different countries and years. Market exchange rates are prone to speculative fluctuation and may thus produce less stable benchmarks compared to PPP rates;
- *Licence bandwidth*: We normalise prices to a per MHz price by dividing them by the bandwidth for the licence; and
- *Population covered:* We express prices in a per capita basis by dividing the licence price by the population covered.

We exclude any outliers (i.e. observations that are far removed from the rest of the sample). In the case of spectrum prices, outliers may take the form of extremely high bids at the time of a telecoms bubble around 2000/2001. Generally, outliers are not representative of spectrum value at large therefore it is important to identify and exclude them from a benchmarking analysis. We use two common methods to identify outliers. An observation is considered an outlier if:

- it lies beyond the 'outer fence' of the sample, with the outer fence calculated as three times the interquartile range (distance between the first and third quartiles) from the first and third quartiles respectively; or
- it lies more than three standard deviations away from the sample mean.

Furthermore, we expect to place greater weight on:

- *European benchmarks* – as there is consistency in spectrum policy across Europe, we would expect market conditions to be more uniform across Europe compared with the rest of the world. Nonetheless, other developed economies are also likely to be a good benchmark for Ireland;
- *Recent benchmarks* – more recent benchmarks are more likely to reflect current market conditions and technical

developments, and hence are more likely to provide a contemporary view on the value of spectrum. This is particularly important for spectrum bands that have only recently been harmonised as equipment cost and the potential impact of scale economies are likely to be relevant factors affecting valuations;

- *Competitive benchmarks* – the more competitive the auction, the more likely final auction prices are likely to reflect opportunity cost of the spectrum concerned. We define a competitive auction as where the licence price for at least one lot exceeded the reserve price for that lot.

In addition to 26 GHz spectrum, we include 32 GHz and 40 GHz spectrum in our sample as these bands are technically similar to 26 GHz and used for commercially similar purposes. Indeed, these frequencies are often auctioned together, for example the UK awarded 10 GHz, 28 GHz, 32 GHz and 40 GHz together in a combinatorial auction in 2008, and the FCC auctioned 28 GHz and 31 GHz spectrum together in Local Multipoint Distribution System auction and re-auction (auctions 17 and 23). Spectrum in the 23 GHz and 40 GHz bands has also been auctioned together in Australia in the 1999 BWA auction.

Our sample consists of 16 observations. Of these, 11 were for 26 GHz band prices. The remainder were 28 GHz and 31 GHz LMDS spectrum, and packages of 26 GHz, 32 GHz and/or 40 GHz bands. Annex B provides further details on the awards we have considered.

A Swiss auction in 2000 of regional wireless local loop licences at 26 GHz sold for a significantly higher price (€0.113 per MHz per capita) than the other awards and has been identified as an outlier. Switzerland's geography is likely to be a factor in the high prices compared to other markets - alternative means of communication such as fibre optic cables are difficult and expensive to install in Alpine regions. The lowest auction price was the British 2008 auction of 10 GHz, 28 GHz, 32 GHz and 40 GHz spectrum which sold for a price of €0.000004 per MHz per capita.

Ten auctions are European (excluding the 2000 Swiss outlier), but only five of them were in the last decade: Austria, the United Kingdom, Ireland, Norway and Sweden. Ten auctions are competitive, of which six are European; however, in many of these auctions, competition was weak.

Looking at the trend in prices over time, prices have fallen significantly since their peak at the turn of the new millennium. In part, this may be due to demand for spectrum for fixed wireless access systems falling off. For example, in the United States, despite initial optimism, Local Multipoint Distribution Services were not ultimately commercially successful.

Figure 4: 26 GHz, 32 GHz and 40 GHz spectrum prices

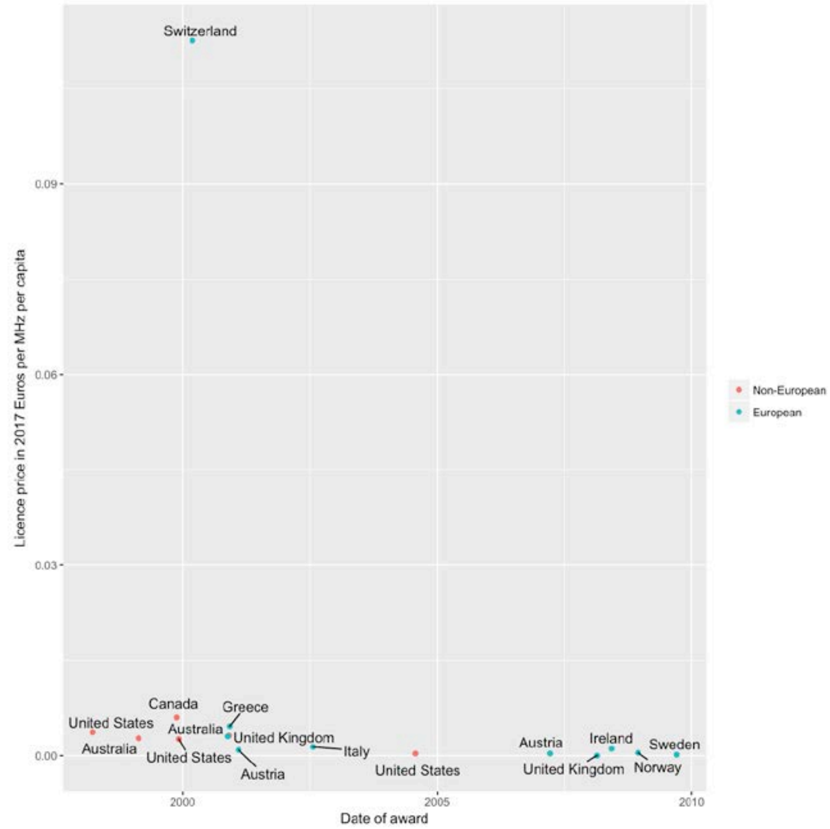

Figure 5: 26 GHz, 32 GHz and 40 GHz spectrum prices (excluding outliers)

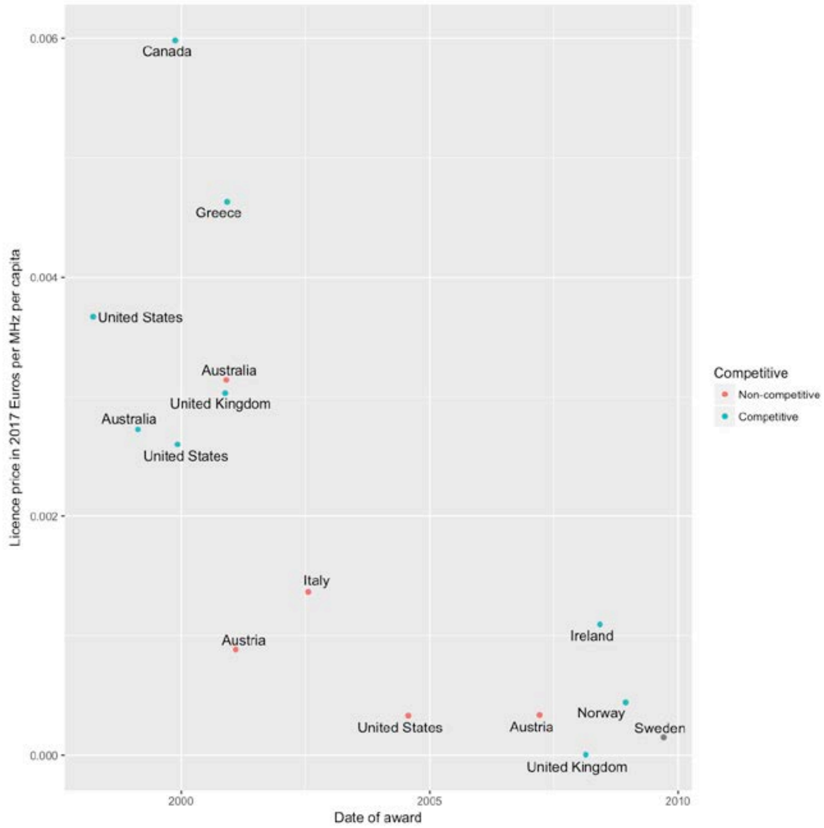

Table 3: 26 GHz, 32 GHz AND 40 GHz spectrum prices (€/MHz/Pop) in 2017 terms

Sample	Mean	Standard deviation	Sample size
All awards	0.00203	0.00183	15
Awards in last decade	0.00041	0.00042	5
European awards	0.00133	0.00154	9

Table 4: 26 GHz, 32 GHz and 40 GHz spectrum prices (competitive auctions only, €/MHz/pop)

Sample	Mean	Standard deviation	Sample size
All awards	0.00269	0.00195	9
Awards in last decade	0.00051	0.00055	3
European awards	0.00184	0.00194	5

All of these benchmarks demonstrate a high degree of variability, reflected in the large standard deviations relative to the means. To put these averages into context, a price of €0.001/MHz/pop corresponds to a price for a 2x28 MHz block in Ireland of approximately €250k (including all future SUFs on a discounted basis); this is close to the minimum price set in the 2008 auction. The European average of €0.00133/MHz/pop implies a price of about €330k per 2x28 MHz block.

4.4.2 Relationship with value of national blocks

Uncertainties in the value of national blocks

The benchmarking above provides estimates of the market value of 26 GHz spectrum and other broadly comparable millimetre bands. However, these bands have been used in a variety of different ways, including both for P2P applications and also PMP and FWA. Therefore, there is a significant degree of uncertainty about what the value of 26 GHz is specifically for P2P links.

The value of national block licences in Ireland is also dependent on the commercial alternatives available to operators. These include:

- Using individual link licences, rather than a national block (as Meteor has done, though is likely to be more expensive that a national block for an operator deploying a large number of fixed links);

- Making greater use of fibre connections, though this may be impractical in some rural areas;
- Deploying P2P links in other millimetre bands.

These alternatives all potentially limit the amount that operators might be willing to pay for 26 GHz national blocks. However, these factors need to be balanced against likely growth in demand for bandwidth on P2P that may have occurred since 2008 and might occur during the course of re-awarded licences.

Recommended minimum price

Given these uncertainties, we recommend that ComReg reapply the minimum price of approximately €245k per block (on a discounted basis including all SUFs at a 9% discount rate) used in the 2008 award. This is below our European benchmark of about €330k per block, suggesting that there should be little risk of choking off demand with a reserve price of €245k per block.

Clearly the 2008 award did not award all of the available spectrum despite setting a minimum price at this level. However, this is not a good reason to reduce the minimum price below the level recommended above (or use a different approach to setting minimum prices). Demand for spectrum for P2P links at 26 GHz is likely to have grown since 2008, in line with general growth in data use and demand for connectivity bandwidth. Therefore, there is a low risk of causing licences to go unsold inefficiently with a minimum price at the proposed level. Moreover, setting a lower annual fee would likely result in higher auction prices (in that bidders will anticipate these annual fees when determining how much licences are worth to them) and less deferment of payments; this would be counterproductive in terms of the benefits of payment deferment in reducing risks for bidders in the context of this particular award.

It might well be possible to set a minimum price above €245k per block without choking off demand. However, there is significant variability in the benchmark data. Therefore, it is difficult to assess how the risks of choking off demand might increase if the minimum price were increased. Given this, we recommend maintaining the minimum price at a similar level to 2008.

As discussed in the previous subsection, we recommend that the minimum price is split across the auction reserve price (which sets the minimum SAF payable directly after the auction, although this could be higher to the extent that there is competition within the auction) and the SUFs. With an auction reserve price of €70k per block (i.e. the minimum SAF, though the auction might determine higher SAFs if there is competition), an annual SUF of around €25k per block per annum (paid in each of the 10 years of the licence) will implement a minimum price of around €245k per block (i.e. the discounted sum of payments is about €245k at a 9% discount rate). This is on the basis that there would be ten SUF payments of €25k, with the first occurring in year one of the licence term, which is a slightly different approach to the fee structure applied for the previous licences awarded in 2008 (which, as we understand it, required licensees to make a total of nine SUF payments, starting in year two of the licence term). However, the proposed payment structure is in line with ComReg's more recent approach to charging SUFs, as in the 2012 MBSA and the more recent 3.6 GHz award.

Therefore, we recommend an annual fee of about €25k per block for a 10-year licence. This would be indexed by CPI over time.

5 Auction format

In this section, we discuss possible auction formats for the 26 GHz band. We start by describing the detailed rules of the previous 2008 award of 26 GHz spectrum. The auction was a two-stage process, with a sealed bid combinatorial auction (SBCA) first determining the number of frequency-generic lots that each bidder won. This was followed by an assignment stage, which determined the contiguous duplex frequency assignments that each winner of generic lots received.

Simplification of the 2008 award

The 2008 auction rules allowed for a flexible division of available spectrum between P2P and PMP uses based on demand revealed in the auction. The 2008 SBCA can be simplified for the current award by excluding this possibility. Although this feature of the 2008 auction was used by bidders, the lots awarded for PMP use were subsequently either returned to ComReg or converted into P2P licenses. As already discussed in Section 2, there is no evidence that potential demand for spectrum for PMP applications needs to be accommodated in the future award.

The case for using a similar approach to 2008

We then discuss the key issues that are important for auction design in the context of this specific award. There are likely to be strong synergies between lots, which suggests the use of a combinatorial format (such as the 2008 SBCA, which we consider remains fit for purpose).

There is no particular need for use of an open auction, given that common value uncertainty is limited and that it is possible to structure a fairly simple sealed bid auction that should yield efficient outcomes given the fairly simple structure of the band being awarded. The additional complexity, cost and time associated with an open auction appears to be unwarranted for this award given there is little reason to expect an open auction to deliver a significantly more efficient outcome than a well-designed sealed bid.

Frequency specific vs frequency generic lots

However, there is a question whether the use of frequency-generic lots with a follow-up frequency assignment stage (as used in 2008) is still appropriate. If the costs of retuning for incumbents in the band is material, such an approach risks unnecessarily costly migration of existing licensees to different frequency assignments and so runs the risk of failing to allocate spectrum efficiently. Some bidders might face difficulties in determining how to bid for frequency-generic lots in the initial stage if the value of these were sensitive to the frequencies assigned in the subsequent stage.

For this reason, if it is found at consultation that at least some existing licensees with an interest in re-award of licences face significant costs of changing frequencies, then we recommend that ComReg consider using a frequency-specific version of the previous SBCA. This would also remove the need for a two-stage process, allocating frequency-generic lots first, then following this with a frequency assignment process. In the event that the costs of changing frequencies are modest, then a simplified version of the frequency-generic SBCA used in 2008 remains more appropriate. As we explain below, there are some theoretical risks of inefficient outcomes associated with the use of frequency-specific lots, so there needs to be sufficient reason to favour this approach over the simpler frequency-generic approach.

We present our auction design proposals as two options:

- **Option A**: a sealed-bid second-price combinatorial auction with frequency-generic lots and a follow-up assignment process (similar to a simplified version of the 2008 award);
- **Option B**: a sealed-bid second-price combinatorial auction with frequency-specific lots.

Annex D provides simple worked examples, showing how bids could be made under each option.

5.1 Auction format in the 2008 award

The previous 26 GHz auction run by ComReg used a sealed-bid, second price combinatorial format. In this subsection, we set out how a simplified version of this auction format works and why it is likely to produce efficient outcomes in cases where lots have strong valuation synergies.

5.1.1 Flexible band plan

The 2008 award allowed for a flexible band plan, in which the auction itself determined the split of the available spectrum between point-to-point (P2P) and point-to-multipoint (PMP) uses. 13 of the 17 2x28 MHz national blocks on offer were assigned to five different bidders, three of which were for PMP, the rest for P2P. As already discussed, PMP licences were either returned or converted to P2P. Therefore, there are currently 12 national block assignments for P2P, split across four operators.

There was no excess demand from bidders' application bids, and so all winning bidders paid the reserve price for the spectrum they were assigned (plus a small additional price paid by Three for its particular frequency option determined by the frequency assignment stage). The eventual outcome was therefore the same (in terms of number of blocks assigned, prices paid, and usage) as would have been obtained with a simpler, fixed band plan in which all spectrum had been offered only as P2P lots.

As there is no evidence of likely demand for PMP in the current award, we will consider only a simplified version of the 2008 auction format with a fixed band plan in which all available spectrum is made available in 2x28 MHz blocks for P2P licences.

5.1.2 Bidding for frequency-generic lots

Under this simplified approach, there would be 19 identical, frequency-generic lots made available in the main stage of the auction. The main stage would determine the number of lots that each bidder wins. There would then be a follow-on assignment stage to determine the specific frequencies to be assigned to each bidder as contiguous duplex frequency ranges corresponding in size to the number of generic lots they had won in the main stage.

In the main stage, each bidder could make multiple, mutually exclusive bids for different numbers of generic lots. At most one of these bids can become a winning bid, so a bidder can indicate the relative value it places on receiving different bandwidths. These bids are submitted simultaneously and cannot be revised subsequently, making this a sealed bid auction.

Each bid is for a package of lots (specifying both a number of lots and a bid amount) that either wins or loses in its entirety; the package cannot be subdivided. For example, if a bidder only makes a single bid for 4 lots, then it cannot win only 3 lots; the bidder will receive either 4 lots or no lots at all. If the bidder explicitly made a second bid, say for 3 lots, then the bidder would win either 4 lots, 3 lots or no lots.

Because bids are for packages of lots that are not broken down, bidders do not face any risk of winning some lots, but fewer than they want (so-called aggregation risk). This means that bids can be made safe in the knowledge that, if successful, they will result in a bidder winning a certain range of contiguous duplex frequencies that can support P2P links with a particular transmission capacity. This is particularly important for the award of 26 GHz spectrum due to the synergies across lots arising if bidders want to support links at particular minimum bandwidths.

5.1.3 Winner determination

Winning bids are selected to maximise the total value of winning bids, subject to awarding no more lots than are available and each bidder winning no more than one its bids. Box 1 below provides a simple example of this **winner determination** process. This determines the number of generic lots won by each bidder.

Box 1: A simple example of winner determination

Suppose there are five generic lots (rather than 19 in order to simplify the example) and three bidders (Bidder A, Bidder B, and Bidder C). The bidders make the following bids:

Lots	A	B	C
1	€3	€2	
2	€4	€4	€5
3	€6	€6	

If Bidder C's bid is accepted (and hence up to three lots can be allocated to the other two bidders), the greatest total value of bids that can be achieved is €12, by giving Bidder A one lot and Bidder B two lots.

If Bidder C's bid is not accepted, the greatest total value of bids that can be achieved is €10, by giving Bidder A two lots and Bidder B three lots, or by giving Bidder A three lots and Bidder B two lots.

The maximum total value of winning bids that can be achieved is therefore £12, and the outcome is to award Bidder A one lot, Bidder B two lots, and Bidder C two lots. There is no alternative feasible combination of winning bids that would generate a higher total.

In the event of a tie in the winner determination between various outcomes that satisfy these conditions and have the same total value of winning bids, a tie selection criterion is used. In the original 26 GHz auction, the number of winning bidders would be maximised amongst the tied outcomes. If a tie was still present, random selection was used.[19]

5.1.4 Second price rule

The prices to be paid by winning bidders are based on the opportunity cost of winning bids – a so-called 'second price' rule. This results in prices that are determined by competition from other bidders for the lots won. The same approach has been adopted in

[19] See Section 4.3.3, ComReg 07/93R.

the recent combinatorial clock auctions used by ComReg (such as the MBSA and the recent 3.6 GHz award).

This approach determines an individual price for each winning bidder for the package of lots that it has won. These prices may not be expressible as a simple price per lot applying uniformly to all bidders, as we explain below.

The **opportunity cost** of a winning bid is the value that is forgone by allocating a particular package of lots to its winner, rather than making those lots available to other bidders. This opportunity cost can be calculated by considering, hypothetically, which bids would win instead if all of the winner's bids were excluded. Specifically, the opportunity cost for winner *X* is defined to be the difference between:

- the total value of revised winning bids if all of bidder X's bids are excluded and the winning bids are re-evaluated; and
- the total value of the original winning bids excluding bidder X's winning bid.

Two simple examples illustrate how this rule works:

- If there were just one bidder, then the opportunity cost of its winning bid would be zero because there would be no alternative bidders to take its lots if it were hypothetically excluded (ignoring for the moment the question of any minimum price that might be in force);
- Suppose that there is a bidder *X* who wins, but a bidder *Y* who makes an identical bid (in terms of bid amount and number of lot) but loses, with bidder *Y* receiving no lots at all. Then the opportunity cost of bidder *X*'s winning bid must be the full amount of its winning bid, as if we excluded bidder *X*, then bidder *Y* can be swapped into bidder *X*'s place.

In the first case, the opportunity cost is zero as the bidder faces no competition at all. In the second case, the bidder faces intense competition having won only on a tie-break. These are polar cases and in general the opportunity cost lies between these extremes, as shown in the more general example in Box 2.

Box 2: A simple example of calculating opportunity cost

Recall the example of winner determination set out in in Box 1, with five generic lots and three bidders (Bidder A, Bidder B, and Bidder C). The bidders made the following bids:

Lots	A	B	C
1	**€3**	€2	
2	€4	**€4**	**€5**
3	€6	€6	

The optimal allocation is to award Bidder A one lot, Bidder B two lots, and Bidder C two lots. Winning bids are shown in the table in bold.

To calculate the opportunity cost for Bidder A, we first need to establish the outcome that would have occurred in the case that all of Bidder A's bids were excluded from the auction (i.e. we only consider the bids from Bidder B and Bidder C). The greatest total value of winning bids from amongst those submitted by Bidder B and Bidder C is clearly €11, achieved by giving three lots to Bidder B and two lots to Bidder C.

We then need to calculate the total value of winning bids in the original outcome excluding the winning bid from Bidder A, which is €12 - €3 = €9.

The opportunity cost for Bidder A (the value denied to the other bidders by awarding two lots to Bidder A) is the difference between these two values:

Opp. cost for Bidder A = €11 - €9 = €2

Performing the same calculations for Bidder B and Bidder C gives opportunity cost for Bidder B of €3, and opportunity cost for Bidder C of €3. Note that these are greater than zero, but below the values (as represented by the bids) placed by the bidders on the lots they won.

A property of the opportunity cost of a winner is that it cannot be negative (as the lowest value that other bidders can place on lots is zero). Moreover, the opportunity cost of a winning bid cannot exceed the amount of winning bid (otherwise it would not have been optimal to select this bid as winning when determining winners).

Pricing on the basis of each winner's individual opportunity costs is usually called **Vickery pricing**. The previous 26 GHz auction, the MBSA and the 3.6 GHz award did not use simple Vickrey pricing, but rather a more complex variation called **minimum revenue core (MRC) pricing**. This requires not just that each individual winning bid pays at least its opportunity cost, but also that every possible *group* of winning bidders pays its *joint* opportunity cost (i.e. the value denied to other bidders from the lots allocated to that *group* of winners).

Joint opportunity cost is defined in a similar manner to individual opportunity cost. The joint opportunity cost of a group *G* of winning bidders is defined to be the difference between:

- the total value of revised winning bids if all bids made by bidders in group G are excluded and the winning bids are re-evaluated; and
- the total value of the original winning bids excluding all the winning bids of bidders in group *G*.

MRC prices are then found by choosing a combination of prices (one for each winning bidder) to minimise the total price paid by all winners, subject to every group of winners paying at least its joint opportunity cost. Note that this includes the trivial cases of single winners as well, who each need to pay at their individual opportunity cost.

It is possible that there may be multiple combinations of prices that are above these opportunity cost floors and also minimise revenue. This situation can arise naturally when there is a group of bidders who collectively have to pay at least their joint opportunity cost, but this exceeds the sum of their individual opportunity costs. For example, suppose there are two just winners, *A* and *B*, who each have individual opportunity costs of 10, but a joint opportunity cost of 28. The total price paid by *A* and *B* must be at least 28, but there are multiple ways of splitting this subject to each paying at least 10. For example, *A* could pay 18 and *B* pay 10, or *A* pay 10 and *B* pay 18 (or any other split between these limits adding up to 28).

The sharing rule used in the previous award (and also the MBSA and 3.6 GHz award) chooses the prices that are closest to the individual opportunity costs, with closeness measured by the sum of squared differences between prices and individual opportunity costs (i.e. Vickrey prices). This is usually called a **Vickrey-nearest rule**. In the example, the joint opportunity cost (28) exceeds the sum of individual opportunity costs (20 = 10 + 10) by 8. The sharing rule splits this across the two bidders, so each pays 18.

The reason for using a second price rule is that it provides good incentives for bidders to bid straightforwardly in line with their valuations. It is not the case that MRC pricing with a Vickrey-nearest pricing provides perfect incentives to bid at valuation, as there are cases in which bidders might seek to adjust their bids to reduce the price they pay. However, due to lack of knowledge about the likely determinants of winning prices in typical spectrum auctions, it is reasonable to expect bidders to find it hard in practice to improve on a straightforward bidding strategy. This issue is rather complex, so is discussed in detail in Annex B.

A further issue to be considered with this approach is the impact of budget constraints. It is not uncommon for management or shareholders to set budget constraints of some form when bidding in auctions. Where a bidder makes multiple bids for different packages, the *differences* between these bids express the bidders *relative* preference between winning different packages. If a bidder includes bids for very large packages – which it possibly might not win – then its valuation for these packages might exceed a reasonable budget constraint and need to be lowered. The bidder can maintain the relativities between its different packages, but might then run the risk that its bids for smaller packages are so low they might not have much chance of winning. Of course, the bidder might choose to give up on bidding for larger packages it does not expect to win to be able to bid more for smaller packages whilst maintain bid relativities between different packages within its budget. Box 3 below provides a simple worked example.

Therefore, a budget-constrained bidder faced with a second price sealed bid auction might need to make some assessment of what packages it thinks it can win. Whilst there are complications for budget-constrained bidders in any auction format, there is a potential argument that an open auction could allow budget-constrained bidders to develop a better understanding of what they might expect to win and tailor their bids accordingly.

However, these considerations are of limited, if any, relevance to the current award, where the value of the spectrum awarded is low by comparison to typical spectrum auctions and bidders are unlikely to face significant budget constraints. Therefore, we do not see the possible advantages of an open format when there are significant budget constraints as being a good reason for using an open format for this award.

In the context of a sealed bid combinatorial auction where bidders may be submitting multiple bids for different packages, incentives for reasonably straightforward bidding are attractive properties of the second price approach. In particular, it should be possible for bidders to submit bids for many packages of interest at valuation (or at least close to valuation), delegating the choice of which package is won to the auction mechanism in the knowledge that the rules entail winning whichever package they would prefer given what they would need to pay to win it. In turn, if bidders' preferences are expressed in an undistorted manner, the process of winner determination will yield an efficient outcome.

Box 3: A simple example of budget constraints

Suppose there are two lots available. Bidder A has a valuation of €90 for two lots and €50 for one lot, but its management has imposed a budget constraint (maximum bid amount) of €60. There is just one other bidder (Bidder B), who bids €15 for one lot (although Bidder A does not know this at the time of bidding).

If Bidder A bids to valuation subject to a ceiling at the budget constraint (i.e. €60 for two lots and €50 for one lot), then its bids demonstrate an incremental value of the second lot of €10, which is much lower than the incremental value of €40 that the bidder actually places on a second lots. If Bidder B bids straightforwardly, Bidder A will win one lot at a price of €0 (there is no value denied to the other bidder, who wins the single lot it bid for), achieving a surplus of €50.

Suppose instead that Bidder A bid in line with value differences (€60 for two lots, €20 for one lot). Bidder A would have been awarded both lots at a price of €15, giving a surplus of €90 - €15 = €75. In fact, Bidder A could have bid anywhere up to €44 for one lot and still won two lots.

Suppose, however, that Bidder B was a stronger competitor and also submitted a bid of €61 for two lots alongside a bid of €15 for one lot. If Bidder A bids according to value differences (€60 for two lots, €20 for one), it will win nothing as the value of winning bids is maximised by awarding both lots to Bidder B. Bidder A could not afford to bid enough to win both lots in this instance. However, it bidder A gave up on the possibility of winning two and submitted a single bid in line with valuation for one lot (€50), it would have won the single lot at a price of €46 (B's incremental value for a second lot) and achieved a surplus of €4.

Without knowing what rival bidders might do and which packages it might expect to be able to win, it can be difficult for budget constrained bidder to judge the right balance between bidding in line with valuations and maintaining value differences. With an open auction, budget constrained bidders might be able to use the information gained to make better judgements over the packages they are likely to win and tailor their bids accordingly. In the example above, if Bidder A sees (in an open auction) that the price for two lots goes above its budget, it may judge that it has little chance of winning the two lots and that it can instead focus on winning a single lot without worrying about affecting its chances of winning the larger package.

5.1.5 Implementation of reserve price

The 2008 award set an auction reserve price of €70k per 2x28 MHz lot (i.e. a minimum SAF, with annual SUFs being additional to this). Both bids and the 'base' prices[20] for generic lots were subject to reserve prices, in that:

- Each bid had to be for an amount no less that the reserve price applied to the relevant number of lots;
- The prices derived from the second price algorithm were subject to a floor equal to the reserve price applied to the relevant number of lots.

Under the approach taken in the 2008 award, it was possible for the second price algorithm to yield a price below the reserve price, as opportunity costs might be set by the incremental value that a bidder placed on additional lots. Whilst each individual bid would need to exceed the relevant reserve price, it was possible that the difference between two bids for packages of different sizes could express an incremental value for additional lots less than the reserve price. For example, bids of €100k for one lot and €145k for two lots are both above reserve, but express an incremental value of only €45k for an additional lot.

More recent awards that have used a second price approach (such as ComReg's CCA for the 3.6 GHz band) have implemented reserve prices in an alternative way. In particular:

- bids are subject to a reserve price floor;
- when determining the winning bids, any unallocated lots are valued at reserve price;
- when calculating opportunity costs for applying the MRC pricing method, each individual and joint opportunity cost is subject to a floor of reserve price.

This approach is slightly different from first calculating MRC prices (without a reserve price floor on opportunity costs) and only then imposing a reserve price floor at the end of the process. The revised method imposes the reserve price floor on opportunity costs from the outset and calculates MRC prices on this basis.

This revised approach to implementing reserve price ensures that lots are only awarded when the incremental value of releasing additional lots exceeds the reserve price. It can be interpreted in

[20] The base price was the price to be paid by a bidder for the package of lots that became the winning bid.

terms of the seller having a value on the lots at the reserve price, and only releasing them if bidders place greater value on the lots.

We recommend that this award use this revised method of applying reserve prices if an auction format with a second price approach (including the sealed bid combinatorial auction) is used.

5.1.6 Assignment stage

The 2008 award used a two-stage process, with the first stage determining the number of frequency generic lots awarded to each bidder. A second stage then determined a contiguous duplex frequency assignment for each winner of the first stage in line with the number of generic blocks it had won.

This second stage was again a second price sealed bid auction, in which each winner made bids for various possible frequency assignment options. Only options compatible with every bidder receiving contiguous duplex assignments were presented to bidders. In addition, these options needed to be consistent with various rules[21] for allocation of any unassigned lots; in the event of allocated lots being awarded for P2P use, any unassigned lots needed to form a contiguous duplex range at the lower end of the band.

Because each bidder was guaranteed to receive exactly one of its frequency assignment options, its bids for these options only expressed a *relative* preference across different frequency assignments. (As a result, adding €1 to every one of a bidder's frequency option bids would have had no effect on the outcome or prices.) There was no requirement on bidders to submit any frequency assignment bids, in which case all bids would all be deemed to be zero, representing indifference across the various frequency options.

The winning frequency options for each bidder were selected by choosing compatible (i.e. non-overlapping) frequency assignment options for each bidder in order to maximise the total value of the winning assignment bids. An assignment price was determined using a second price method (again a MRC price using a Vickrey nearest rule).[22] Winners paid the sum of the prices arising from the first and second stages of the auction, and annual usage fees set by ComReg.

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[21] See section 4.4.1, ComReg 07/93R. These rules depend on the mix of lots awarded as P2P and P2MP.

[22] In the 2008 award, O2 (now Three) paid an assignment price of €30,679, whilst Vodafone paid €158,435.

5.1.7 Summary

It is feasible to reapply the second price sealed bid format that was used in 2008 to the present award. However, this can be considerably simplified, as there is no evidence that it is necessary to make provision for PMP use in the band through a flexible band plan.

We would also recommend making a minor modification of the method by which reserve prices are applied to make the pricing methodology, consistent with that used in ComReg's recent CCAs. Otherwise, the rules still remain largely fit for purpose. The next section sets out other auction design considerations that may arise in this award.

5.2 Auction design considerations

Our starting point is that the auction design should take account of the following three key issues:

- If spectrum is offered in 2x28 MHz blocks, some bidders are likely to want to aggregate multiple contiguous blocks to allow for higher capacity P2P links, creating strong synergies across blocks. Blocks must also be assigned contiguously in order for them to be usable. If a bidder receives fewer blocks that it expects, this would mean that it would be restricted in the bandwidth of links it could deploy over a national block licence. Whilst it would remain open to the bidder to deploy links under the individual link-licensing regime, clearly this would be a significant restriction; in the worst case this could make spectrum unusable for that bidder. Therefore, synergies are likely to be strong in this. This situation was noted in the 2008 Information Memorandum[23];
- Existing licensees may face some additional costs if they were to move from existing frequency assignments within the band, and there is likely to be benefit in minimising movement as much as possible. At the same time, clearly no guarantee can be offered that it will be possible for existing licensees to maintain their frequency assignments, as this depends on how much spectrum each bidder wins. Existing licensees could face some retuning costs if there is any change to their assigned frequencies. Also, there may be tuning range limitations on the radios used in links, which

[23] "The Award of National Block Point to Point and Point to Multipoint Assignments in the 26 GHz band", ComReg 07/93R, January 2008, page 5.

could create a situation where higher adjustment costs are faced if these limitations are exceeded and radios need to be replaced; however, even in these cases, much equipment (e.g. antennas etc.) could be reused;

- The previous 26 GHz award held in 2008 used a sealed-bid format as it was considered that common value uncertainty was likely to be limited and that, given this, the additional complexity of an open award was unwarranted. It remains the case that bidders are likely to use national blocks for point-to-point licences in different ways depending on the organisation of their networks, creating idiosyncratic variations in value of spectrum across bidders that will tend to mask any sources of common value uncertainty. However, for this award the potential migration of the 26 GHz band from use for point-to-point microware links to 5G at some uncertain future date is a common uncertainty facing all licensees that could, arguably, be relevant to the choice between a sealed bid and open auction.

While the first of these issues existed for the 2008 award of the 26 GHz band and is dealt with by the SBCA, the others have arisen since and are specific to the current award. As such, modifications to the previous award or alternative design formats may be advisable. We consider the implications of each of the three issues in turn.

5.2.1 Implications of synergies and package bidding

The first issue – strong synergies across lots – requires use of an auction format that involves package bidding, so that bidders do not face aggregation risks arising from the possibility winning some, but not all, of their target lots. This was a feature of the 2008 SBCA. Package bidding is also a feature of open auctions such as the combinatorial clock auction (CCA), which ComReg has recently used for the award of 3.6 GHz spectrum and previously for the MBSA award, and the simple clock auction.

The presence of strong synergies creates difficulties in using an open auction such as a simultaneous multiple round auction (SMRA) that does not use package bids. With an SMRA, standing high bidders are determined for each lot separately, so a bid is not for a package of lots. For instance, consider a simple example in which there are 10 lots and three bidders who each want 4 lots, but if a bidder wins fewer than 4 lots this is of little value. Bidding would proceed with each bidder actively bidding for 4 lots, and being standing highest bidder on either 2, 3 or 4 lots at the end of each round (depending on the selection of standing highest bidders). The first bidder to drop out will find itself stranded as a standing highest bidder on 2 lots on which it would not be overbid, with the other two bidders winning their target 4 lots. This means that the winner of 2 lots will pay in excess of its valuation.

It is possible to modify the rules of an SMRA to try to reduce these risks:

- Standing high bids can be determined by breaking ties between bids at equal prices in a manner that reduces fragmentation; and
- Bidders might be allowed to withdraw bids in limited circumstances, for instance if the number of lots won fell below a minimum threshold nominated by the bidder at the start of the auction.

While such modifications might reduce risks for bidders, an SMRA could still yield inefficient outcomes. For instance, even if the stranded 2-lot winner in our example could withdraw its standing high bids, this would leave those lots unallocated; however, other bidders might be willing to take one or both of those lots at a lower price.

This example illustrates a further consequence of the strong synergies between lots: the auction format needs to allow for non-linear pricing, otherwise there is a risk of inefficient outcomes. Any format that imposed a requirement that all bidders paid a common price per lot would risk a scenario in which there is competition between bidders wanting multiple lots that sets a price per lot exceeding the valuation of bidders wanting a smaller number of lots or just one lot; in this case, lots would inefficiently go unsold. Therefore, approaches such as a simple clock auction or a sealed bid auction that imposes a uniform price per lot are not appropriate to this award.

The SBCA used for the 2008 award of 26 GHz spectrum avoided this risk of inefficiently unsold lots through the use of core pricing that determined a specific price for the package won by each winning bidder, rather than determining a price per lot applied uniformly across all bidders.

Therefore, we conclude that whatever format is used – open or sealed bid – should ideally allow for package bidding and not impose linear prices (i.e. uniform per lot prices for all bidders) if efficient outcomes are to be achieved.

5.2.2 Implications of costs of changing frequency assignments

The previous award used a SBCA with frequency-generic lots, followed by an assignment round that determined the frequencies allocated to winners of generic lots. Whilst this approach may be appropriate for the current award (as we discuss below), we need to consider whether this may expose bidders to risks if incumbents face significant costs of moving frequency assignments. In particular, there could be a situation in which an existing licensee would face some costs of retuning radios in links within the limits of the equipment, and higher costs if those limits were exceeded and equipment needed to be replaced. We understand the typical tuning range to be about 300 MHz, in comparison with the 504 MHz range available for award, so it is possible that radio replacement could be required in some cases if incumbents were shifted by a sufficient amount.

It is difficult to reach any definite conclusions about the need for radio replacement, as this depends on how close incumbents are to the edge of the tune ranges of their existing equipment. Moreover, there may be greater re-tuning flexibility for lower bandwidth links that use less than the full width of a licensee's allotted spectrum. Therefore, the details are likely to depend on the specifics of the current links and equipment in use for each licensee and the exact frequency range that the incumbent might need to move to; this could be quite different for different licensees. Therefore, the materiality of these adjustment costs is a matter for consultation with existing licensees.

If frequency adjustment costs are significant relative to the likely value of these licences, then it might not be appropriate to expect bidders to make bids on a frequency-generic basis, first allocating frequency-generic lots and afterwards determining frequency assignments given the number of generic lots assigned. To adopt this approach would face bidders with the problem of deciding how much generic lots would be worth to them without knowing what re-tuning might be required when specific frequencies were subsequently assigned. This would risk inefficient outcomes and incurring unnecessary adjustment costs.

Notice that this difficulty cannot be overcome through a requirement that existing licensees be re-awarded existing frequencies wherever this is possible. With a two-stage process with frequency-generic lots, there is no guarantee that the first stage would create an outcome in which existing frequencies could be reassigned even if each licensee won exactly the same number of 28 MHz blocks that it current holds; if there were new demand for 4 or more blocks, this would require re-organisation of the band to consolidate existing unassigned spectrum, so at least one incumbent would need to move.

Therefore, we propose an alternative option **(Option B)** for an auction that allows market determination of the frequency plan in a single stage by using frequency-specific lots. This would then allow any required re-tuning to be undertaken by whichever existing licensees were able to undertake that at least cost and thereby minimise overall adjustment costs. Bidders' valuations could then reflect the different re-tuning costs of different options, which would avoid facing bidders with unnecessary risk and ensure that the auction prices were reflective of retuning costs.

We would emphasise that this approach based on frequency-specific lots would not show undue preference to incumbents. In particular, no additional rights would be granted to incumbents beyond the life of existing licences by this approach. Rather, the use of frequency-specific lots ensures that all bidders – both existing licensees and new bidders – would be able to express their preferences and compete both over the number of blocks they receive and the frequency assignment for those blocks.

Option B would not be excessively complex. First, it avoids any need for a follow-up stage to determine frequency assignments, as this would all be achieved in a one-shot process. Second, bidders would not need to make an excessive number of bids to represent demand for all packages of interest. For example, if a bidder want to bid for a 4-block package, but did not have any frequency preference, then the bidder could make 15 equal bids (representing the 15 different possible locations of a contiguous 4-block package amongst the available 19 lots). Counting all the possible packages with between 1 and 5 blocks gives 85 possible packages. Therefore, it would entirely feasible for bids to be submitted in a simple form or spreadsheet.

5.2.3 Open auction vs. sealed bid auctions

The 2008 award used a sealed bid auction format (the SBCA). The additional complexity of an open auction was deemed unnecessary as common value – the usual reason for needing open auctions – was judged to be relatively unimportant. This is because bidders were likely to have very different valuations for national block licences depending on how they each wanted to use point-to-point links within their networks and what use they might want to make of the individual point-to-point link licensing regime. Therefore, even if there were common uncertainties facing bidders, these were likely to be masked by idiosyncratic differences in how they might use spectrum.

This situation is still largely the case. However, one additional source of potential uncertainty is the possibility of refarming the 26 GHz for 5G use. Although the timetable for 5G use is currently unclear, there is a high probability that the 26 GHz band will be mandated for 5G use within the horizon of the usual life of spectrum licences issued by ComReg (15 years). The potential impact of use of the 26 GHz for point-to-point links would arguably be a source of common uncertainty for all licensees, possibly suggesting that an open auction format might be appropriate.

However, we should not overstate this common risk. First, it is likely that a significant degree of coexistence will be possible between existing P2P links and any new 5G use of this band. P2P links are largely deployed in rural areas for backhaul purposes and interference possibilities are limited by the use of tightly focussed beams. In contrast, 5G use of 26 GHz (and millimetre bands more generally) would likely be for very short range, high bandwidth areas probably inside or in dense urban areas.

Second, it might be possible for ComReg to issue a somewhat shorter licence than it usually would, to mitigate this risk for bidders. We have recommended a 10-year licence given the very specific circumstances of this award.

Third, it would always be open to ComReg to refund licensees in the unlikely event that some curtailment of their usage rights might be needed to implement future obligations to make 26 GHz available (possibly in part) for 5G.

We note that open awards may be desirable where is a high degree of complexity, with many lots, multiple bands and possibly many categories of lots (if lots are differentiated or regionalised). In this case, there is a role for an open auction in allowing bidders to identify potential market clearing outcomes and to refine their valuation and business modelling to consider those likely outcomes. Without some guidance on what they might win, it might be unreasonable to expect bidders to consider myriad possible outcomes. To try to achieve a similar outcome with a sealed bid might involve bidders having to value an unreasonably large number of packages and submit many bids. However, this situation clearly does not arise in this award. Even if bids were made for frequency-specific lots, we show below that there is a small number of packages of lots that bidders would need to consider.

Finally, a key consideration for any auction is the risk of collusive behaviour by some bidders that would distort the outcome of the award. With open auctions, it is possible that one or more bidders might attempt to coordinate with, or influence the behaviour of, other bidders via signals in their bidding behaviour that could be picked up in the round-by-round information that is released. With a well-designed open auction the opportunities and incentives for signalling can be significantly (although not completely) limited, to the extent that the risks of collusion are sufficiently low so as to be acceptable in scenarios where they are outweighed by the benefits of using an open award. With a sealed-bid format, the risks associated with inferring behaviour round-by-round are removed,[24]

[24] Note that using a sealed bid auction only prevents coordination through signaling via the bids submitted. It does not eliminate the risk of bidders coordinating via other means outside of the bidding process, although this would as standard be prohibited by the auction rules with severe consequences for any participant found to be in breach of those rules.

as there are no opportunities for bidders to observe others' behaviour and then react to it. In the context of the current award, since we do not consider there to be much benefit from having an open auction, the use of a sealed bid format minimises the risk of collusion.

Overall, we consider that it would still be appropriate to use a SBCA approach, and that the 5G curtailment risk is not sufficiently important to recommend switching to an open format, especially if mitigation measures are taken to reduce this risk. These measures comprise issuing shorter licences than typical and structuring payments so that they are more spread over time than would usually be the case.

5.3 Alternative auction formats

Given the discussion above, we consider that the complexity of an open auction is not justified for this band, as there are good alternative sealed bid approaches that can meet ComReg's statutory objectives by delivering efficient outcomes. There are two main options that we set out below:

- **Option A**: an updated and simplified version of the second-price sealed bid combinatorial auction of frequency-generic lots used in 2008 (as discussed in Section 2.3 above); or
- **Option B**: a similar second-price sealed bid combinatorial auction, but using frequency-specific lots.

If it is found that retuning costs could be significant relative to the likely value of the spectrum to potential bidders, then we recommend that ComReg adopts the frequency-specific approach (Option B). Otherwise, unless there is a clear and strong case for the use of frequency-specific lots, we would recommend that ComReg adopt Option A.

5.3.1 Frequency-specific SBCA

This approach does not require a frequency assignment stage and there would be just one stage of bidding. Bidders would be invited to submit a list of package bids, with each bid setting out the specific lots to be included in the package and the associated bid amount. The packages that could be bid for would be restricted based on the requirement that only contiguous lots could be included in a package. Assuming that 19 lots will be available, with a competition cap of 5 lots there would be at most 85 frequency specific packages that could subject to bids.

Winning bids and prices for winners would be determined using MRC pricing with a Vickrey-nearest sharing rule, just as with a frequency-generic auction. The discussion of winner determination and pricing in Section 5.1 applies in exactly the same way, without modification, to an auction with multiple differentiated lots.

Risks due to partial expression of frequency alternatives

A concern that this approach raises is the risk that bidders fail to make a sufficient number of bids, only bidding for a limited number of frequency options and leading to an inefficient outcome. A specific example of this general concern is that incumbent licensees might bid only for their existing frequency allocations. This could result in a bidder failing to be allocated any lots at all due to all of its bids colliding with frequencies subject to other bids; there could also be an outcome in which unsold lots are fragmented across the band. Had the bidder bid for a wider range of frequency options then it could have been accommodated alongside other demand.

This problem can be largely resolved by putting bidders on notice of this risk and explaining the importance of bidding for all frequency options of potential interest, not just preferred options. Furthermore, appropriately presented bid forms or bid software could help. In particular:

- If a bidder wants to bid for an *n*-lot package, it is required to enter a default bid amount that applies to all *n*-lot packages regardless of their specific frequencies;
- If a bidder wants to bid a different amount for a particular *n*-lot package at specific frequencies, then it must explicitly override the default bid;
- Similarly if a bidder did not want to bid a particular *n*-lot package at specific frequencies, then it must override the default *n*-lot bid and rule out this particular package.

We consider that this approach would largely eliminate the risk of a bidder failing to bid on a sufficient variety of frequencies through error. It is not overly complex, as any *n*-lot default bid would require at most 19-*n* of these override bids if a bidder had complex preferences over frequencies.

Potential exclusionary bid strategies with frequency-specific lots

A further theoretical risk from the use of frequency-specific lots is that this enhances possibilities for exclusionary bidding. Consider the following highly simplified example. Suppose that there are 8 lots available and that bidder *A* wishes to win 4 lots. Bidder *B* also wants to acquire 4 lots (and no interest in any fewer number), but has a lower value than bidder *A*. Suppose that bidder *A* also has a subsidiary objective of excluding bidder *B* and has an enhanced valuation for outcomes in which bidder *B* is excluded.

With frequency-specific lots, it would be possible for bidder A to make a four-block bid at positions 3 though 6 (inclusive). This would leave two fragmented pairs of lots unallocated (at positions 1 and 2, and positions 7 and 8). It would not be possible to satisfy bidder B's demand for 4 contiguous lots. Bidder A would pay the opportunity cost of its winning bid, which in this case is just bidder B's bid.

Now consider how bidder A might bid with frequency-generic lots. In this case, bidding for 4 generic lots would not be sufficient to exclude bidder B. It would be necessary to bid for (at least) 5 lots. If bidder A were successful in excluding bidder B, it would again pay bidder B's bid.

Therefore, if bidder A excludes bidder B it pays the amount of bidder B's bid regardless of whether frequency-specific or frequency-generic lots are used. However, in the case where frequency-generic lots are used, it is necessary for bidder A to bid for at least 5 lots in order to exclude bidder *B*. If there were other bidders involved, bidding for a greater number of blocks would have the potential to affect bidder A's winning price. For example, suppose that we introduced two additional bidders *C* and *D* who each bid for two lots each. In the frequency-specific case, these bidders could be accommodated in the winning outcome (at position 1 and 2, and position 7 and 8). However, in the frequency-generic case, if bidder *A* bids for 5 lots to try to exclude bidder *B*, this will also entail one of *C* or *D* losing (whichever had bid least). This would increase bidder A's winning price (by an amount equal to the lowest of C's and D's bids). In this simple example, we find that it is more expensive for bidder *A* to exclude bidder *B* when frequency-generic lots are used, as the strategy of fragmenting the band – possible with frequency-specific lots – if not available to bidder *A.*

There are close parallels between the issue of a bidder not making a sufficient range of alternative frequency-specific bids to reflect its preferences and so affecting the auction outcome, and the possibility using frequency-specifics bids for exclusionary purposes. In the latter case, a bidder is *deliberately* limiting its set of frequency-specific bids with a view to creating fragmentation of the band that excludes a rival.

This risk should not be overstated, as the example above requires particular assumptions and in many practical situations the ability of a bidder to use frequency-specific bidding to exclude rivals is likely to be much more limited. In particular, the example above relies on bidder *A* being able to acquire a large proportion of the band, with the result that the demand of the bidder targeted for exclusion (bidder *B*) is large relative to the remaining number of blocks *not* acquired by bidder *A*. In this case, bidder *A* wants 4 of the 8 available blocks, leaving just 4 blocks remaining for bidder *B*. This gives bidder *A* the power to exclude bidder *B* (with a sufficiently high bid) by bidding in the centre of the band. However, if we modify the example by supposing that there are a greater number of lots available (in particular 11 or more lots), then bidder A cannot exclude bidder B regardless of where it locates its bid in the band.

Therefore, with a greater number of lots available relative to the demand of individual bidders, it becomes very difficult indeed to use frequency-specific bids to fragment the band as exclude bidders. This is because, regardless of where a bidder bids within the band, there are a sufficient number of contiguous lots left to accommodate other bidders' demands. Also, with a greater number of bidders with varying demands, the impact of bidding at specific frequencies becomes more difficult to anticipate. In the present case, with 19 lots and a cap on demand of 5 lots, it appears very difficult to use frequency-specific bids in this manner to fragment the band with a view to excluding other bidders.

Overall, the concerns expressed above about possible inefficient outcomes if bidders do not bid for all relevant frequency alternatives and the possibility of exclusionary bidding (though in practice only where individual demands are a large proportion of the total available lots, which is not the case) are not sufficiently serious to rule out the use of the frequency-specific lot approach at this stage. However, equally because of these potential issues it is important that frequency-specific lots are only used in preference to the simpler frequency-generic approach if there is a clear need.

Implementation issues

There are no particular issues with a frequency-specific SBCA, as the requirement to submit bids only for contiguous lots within the limits of the competition cap greatly limits the number of possible packages. Bid data could be collected through an online portal. However, given the simplicity of the bidding process, bidders could also be provided with simple spreadsheets to complete and return to ComReg by a specified deadline.

Solving for winning bids and MRC prices would present no particular computational challenges given the likely number of bidders for these lots.

5.3.2 Alternative open formats

We do not consider that there is a strong case for an open auction, as we have explained above. Nevertheless, in this section we consider possible open auction formats that could be used for this award.

SMRA

The simultaneous multiple round ascending (SMRA) auction is a commonly used format for spectrum auctions. It involves repeated rounds of bidding, with bidders being declared standing highest bids on particular lots until they are overbid at a higher price. All lots remain in play until the auction closes (the 'simultaneous' aspect of the auction).

The SMRA would be a feasible to use with frequency-specific lots. However, the SMRA does not allow for package bids. It is possible that a bidder could be standing highest bidder on a number of lots, and then be outbid on some, but not all of these lots. Given the strong synergies across lots that are likely to exist for some bidders, there is a risk of winning a subset of lots at a price above the value of those lots to the winner. This risks inefficient outcomes.

A further problem with an SMRA with frequency-specific lots is that it is not possible to guarantee that each bidder *wins* a contiguous span of (duplex) frequencies, even if we impose a rule that bids can only be made for contiguous blocks. For example, suppose that one bidder bid for four contiguous blocks, but was overbid on the middle two of these; this would leave the bidder winning only the outer two of the four blocks.

Although these problems could be somewhat ameliorated by providing rules for limited withdrawals of standing high bids, they cannot be eliminated and risks creating significant additional complexity in the award process. Therefore, the SMRA with frequency-specific lots is not a viable candidate format for this award.

Simple clock auction

A clock auction would provide a feasible approach if frequency-generic lots are used. At each round, the auctioneer would announce a price per lot and each bidder would say how many lots it wanted. If total demand exceeded 19 (the number of lots available) there would be another round with a higher price per lot. A bidder would not be able to strictly increase the number of lots it demanded from one round to the next. Rounds would continue until total demand did not exceed the number of lots available.

The advantage of the clock auction over the SMRA is that bids would be for packages of lots. This removes aggregation risks. Moreover, a clock auction of frequency-generic lots can guarantee that each bidder is assigned a contiguous range of (duplex) frequencies, as this can be imposed as a restriction in a follow-up frequency assignment stage (as done in the 2008 auction).

The main problem with a clock auction is that it could result in inefficiently unsold lots when some bidders have strong synergies. This arises because the clock auction imposes a uniform price per lot for all winners, regardless of the number of lots that each winner might receive.

Consider the following simple example. Suppose that there were four bidders each competing to win the maximum number of lots under the competition cap (i.e. five). There would be excess demand of (at least) one lot as long as all four bidders kept each bidding for five lots. Competition between these four bidders could increase the clock price to a level at which other bidders interested in smaller numbers of lots had all dropped out. Now suppose that a five-block bidder drops out and the auction closes. There would be 15 lots assigned and four unassigned lots. However, despite potential demand for these four unassigned lots from other bidders, they would be at too high a price for these other bidders to be willing to accept them.

This problem is avoided through the use of the combinatorial auctions that do not impose linear pricing, i.e. that winning prices derive from a common per lot price applied uniformly to all winners. In the simple example above, to avoid inefficiently unassigned lot we need to be able to offer smaller packages at a discount (on a per lot basis) relative to the price established by competition between five-lot bidders. The sealed bid combinatorial auction with a second price rule is able to do this as it does not impose linear price, but rather derives winning prices for the relevant opportunity costs for each winner. Amongst open auctions, the combinational clock auction (CCA) and combinatorial multiple round auction (CMRA) also have similar properties and so are to be preferred to a simple clock auction for this award.

Finally, a clock auction would not be appropriate for the case of frequency-specific lots, as then it would be necessary to form 19 lot categories each consisting of a single lot. Each category would require its own separate clock price. It would be difficult to increase prices in a manner that reduced demand progressively; the various lots would be close substitutes for many bidders, who would tend to shift demand around depending on their relative prices.

Combinatorial Clock Auction

A better choice of open auction format is the Combinatorial Clock Auction (CCA), which has been used by ComReg for other recent awards (the MBSA in 2012, and the more recent 3.6 GHz band award). It is possible to use a CCA with frequency-specific lots as well as frequency-generic lots (in which case there would be one category containing 19 lots).

A CCA would be a two-stage process, with rules similar to those used for the main stage of the recent 3.6 GHz band award in Ireland.

The first stage is essentially a clock auction. During the clock rounds, bidders would bid for packages of lots at prices set by the auctioneer. The price of a lot category would be increased for the next round in the event that there was excess demand for the lot at previous round prices.

Following a clock round in which there was no excess demand for any lot at prevailing round prices, the clock rounds would end and a single supplementary bids round would be run. The supplementary bids round has similarities with the SBCA was have set out above as the preferred auction format for this award.

The supplementary bids round would allow bidders to:

- increase the bid amounts submitted for packages bid for in the clock rounds; and/or
- submit bids for additional packages not bid for in the clock rounds.

Bidders are therefore able to fully represent their valuations for packages of lots in which they might be interested but not bid in the clock rounds.[25]

If using a CCA, we would recommend applying the same activity rules as for the 3.6 GHz award:

- Bidding behaviour in the clock rounds would be constrained through the use of revealed-preference based activity rules, whereby bidders would only be allowed to increase the number of lots they bid for (relative to the package bid for in the previous round) if prices are such that doing so would be consistent with value differences across packages implied by the bidders bid decisions in previous rounds where it reduced the eligibility (number of lots bid for). Allowing for so-called relaxed bids (bids for packages larger than current eligibility) would be appropriate in this situation as it would allow bidders to bid according to valuation in a setting where (due to retuning costs) there may be a preference to reduce the number of lots bid for in a particular (preferred) part of the band before switching to larger packages located elsewhere in the band but where retuning costs are higher.
- Supplementary bid amounts would be constrained based on value differences implied by bidding behaviour in the clock rounds, applied through the use of relative caps with respect to packages bid for in rounds where the bidder reduced eligibility, and also with respect to the package bid for in the final clock round (the final price cap).

These activity rules (alongside the winner and price determination rules) are designed to incentivise bidding straightforwardly according to valuations.

The process of determining winners and prices in the CCA would be essentially identical to the proposed SBCA described already.

Whilst it would be quite feasible to use a CCA with either frequency-generic or frequency-specific lots, in the case of frequency-specific

[25] The relatively small number of packages that bidders could bid for means that there would be no computational complexity that would require a limit on the number of supplementary bids that could be submitted (as was the case for the 3.6 GHz award where bidders could submit bids for up to 1,000 packages), so bidders would be able to enter bids for all packages of interest.

lots the clock phase of the auction is unlikely to be particularly useful in terms of price discovery. In particular, prices will rise where bidders' frequency ranges overlap, encouraging bidders to shift within the band to try to reduce overlap. However, some of this overlap will occur at random, as bidders try to test out positions within the band where they might fit in. Therefore, there might be a tendency for some prices to rise because of bidders trying to grope towards an outcome. This is largely a result of bidders only being able to make a bid for one package in each clock round.

Contrast this situation with the frequency-specific SBCA, where bidders state all the alternative frequencies and package sizes they might accept. The winner determination algorithm then undertakes the patching together of bidders' demands in a consistent manner. This patching together is possible expressly because we have information available about alternative frequency assignments for each bidder.

This issue would be addressed by the use of a combinatorial multiple round auction (CMRA) rather than a CCA, as the former allows for multiple frequency assignment alternatives to be expressed in each round. We discuss this format below.

Combinatorial multiple round auction

The CMRA has been used in Denmark for the recent award of 1800 MHz spectrum. The CMRA follows a basic clock auction structure, but allows bidders to submit multiple mutually exclusive package bids each round. One of the bids (the 'headline bid') must be at clock prices, and will determine the eligibility of the bidder in the following round (the minimum of the bidder's eligibility in the round and the bidders' activity in the round). The headline bid can be zero if the bidder does not wish to make any bids at clock prices (and this is the default bid if the bidder does not make any bids in the round).

A bidder can submit bids for other packages of lots alongside its headline bid. However, all bids submitted in a round must satisfy the constraints that bid amounts:

- cannot exceed clock prices
- must be above any relevant reserve price; and
- must satisfy revealed preference constraints arising from rounds in which the bidder reduced eligibility (which are analogous to the relative caps used in a CCA).

Constraining bids to not exceed clock prices ensures that bids are increased progressively, if required in order to outbid competitors.

Unlike the clock stage of the CCA, the CMRA does not end when there is no excess demand at clock prices (from headline bids). This is important, because the CMRA does not include any further stages, and hence bidders must submit all of their bids during the clock rounds. Instead, the CMRA ends when it is possible to accept one bid from each bidder (which can be a bid for zero lots if the bidder made a zero headline bid, but not otherwise) and this achieves the maximum possible value (relative to accepting bids without necessarily including a bid from each bidder).

One implication of the closing rule is that bidders always have an opportunity to bid back if they are not winning with one of the bids they have submitted. Therefore, bidders have less pressure to make bids for all possible targets, and can instead introduce these progressively in response to changes in the clock prices.

Another implication is that the auction might end even if there is excess demand at clock prices, if it were possible to achieve the maximum possible value by accepting a bid from each bidder without necessarily including all the headline bids. This is can help to resolve coordination problems where the headline bids from different bidders clash on the same lots, but where such bidders would be equally happy to acquire different lots instead in a way that would allow for accommodating demand from all bidders.

The closing rule also implies that the auction might continue even if there is no excess demand at clock prices i.e. in the case where bids at clock prices would be outbid by other bids, requiring some prices to increase. Therefore, determining whether any lots require a price increase (and hence whether or not the auction ends) does not simply rely on assessing excess demand at current clock prices. Instead, the CMRA determines which lots need a price increment by checking which bidders would be at risk of losing, and then determining the lots for which demand at clock prices from these bidders clashes with the bids from other bidders.

The CMRA has the desirable property that bidders may the amount of their winning bids, though these amounts are determined by competition with other bidders. This contrasts with the CCA, where a bidder bidding straightforward could make a bid for a package of lots, but end up paying less than this due to the second price rule. Therefore, the CMRA may be more appropriate if some bidders could be budget constrained.

Open formats – conclusions

On available evidence, there is little need for an open auction as it is unlikely that there will be strong common value uncertainty amongst bidders. Also, if a combinatorial auction format is used, there are a limited number of packages that bids could be made for, even with frequency-specific lots; therefore, there is no need to use an open auction to allow bidders to narrow down a set of packages which might be likely to win, as bidders can simply make bids for all possible packages of interest.

Nevertheless, if evidence were to emerge at consultation suggesting that common value uncertainty were sufficiently significant, then an open format might be considered. If an open auction were required, a good candidate would be the CMRA. This could be used with either frequency-specific or frequency-generic lots. The CCA is a god alternative if the case of frequency-generic lots, though might work less well with frequency-specific lots.

6 Summary of recommendations

This section provides a consolidated list of our recommendations:

- The award would be for 19 blocks of 2x28 MHz duplex spectrum for P2P use;
- Licences should be subject to a usage condition to allow technology-neutral deployment of P2P links, but not mobile or PMP use;
- Licences should last for 10 years;
- The overall minimum price (i.e. the discounted sum of the lowest possible spectrum access fee (SAF) – set by the auction reserve price – and ongoing annual spectrum usage fees (SUFs)) should remain at a similar level to the 2008 auction. This is below current benchmarks obtained from competitive auctions of similar bands elsewhere.
- We recommend an annual spectrum usage fee (SUF) of around €25,000 per block, indexed by inflation. This means that the overall minimum price is mainly loaded on the SUFs, rather the reserve price.
- An auction reserve price of about €70,000 per block should be sufficient discourage frivolous applications, with the auction price determining a spectrum access fee for each winner (payable shortly after the auction) at least equal to the reserve price;
- There is little need for an open auction process and we recommend the use of a second-price sealed-bid combinatorial auction (SBCA) similar to that used in 2008;
- We propose two specific options depending on whether existing licensees face material costs of frequency adjustments (as compared with the likely price of licences), though Option A should be default choice;
- Option A is for a SBCA of frequency-generic lots, followed by a one-shot frequency assignment stage (similar to the 2008 award, except without the complication of possible PMP lots);
- Option B is for a SBCA of frequency-specific lots (with no need for a follow-up assignment stage, and again without the possibility for PMP lots);
- The minimum revenue core price algorithm proposed for the SBCA is essentially the same as that used in 2008, though we recommend that the implementation of reserve pricing within the algorithm is updated to use the approach taken in the recent 3.6GHz and MBSA auctions.

Annex A Charging structure for individually licensed P2P links

Individual point-to-point links are deployed at the top end of the 26 GHz band across six 2x28 MHz blocks. As of September 2017, there were 384 links licenced to eight licensees.

Individual point-to-point links may have a channel spacing of 3.5 MHz, 7 MHz, 14 MHz or 28 MHz. This compares with the maximum channel spacing of 56 MHz for the National Block licences. The overwhelming majority (354) of links have a channel spacing of 28 MHz. Twenty-eight links have a channel spacing of 14 MHz and only two links have a channel spacing of 7 MHz. There are no links with a channel spacing of 3.5 MHz.

Annual fees for a 26 GHz point-to-point radio link are set out in the Wireless Telegraphy (Radio Link Licence) Regulations 2009. The annual fee depends on the bandwidth of the link, and whether the licensee has multiple links in the same path or the links are in a "Congested Frequency Band Area". The fees are summarised in the table below, where:

- *"A High Usage Path is a Radio Link Path upon which the Licensee has five (5) or more Radio Links"; and*
- *"The Congested Frequency Band Area is … the geographic area as defined by National Grid 3122 and 3123 (Ordnance Survey of Ireland). A Radio Link is within this area when one or both of its' specified fixed points is located in this geographic area."*

Table 5: Annual fee for a 26 GHz Point-to-Point radio link (source: Wireless Telegraphy (Radio Link Licence) Regulations, 2009)

	Bandwidth (MHz)		
	BW ≤ 3.5	3.5 < BW ≤ 20	20 < BW ≤ 40
Not on a High Usage Path or in the Congested Frequency Band Area	€750	€825	€900
On a High Usage Path or in the Congested Frequency Band Area	€900	€990	€1,080

In June 2008, ComReg awarded 26 GHz National Block licences by auction. Each 2x28 MHz block attracted an upfront fee of €70,000 plus annual fees of €20,000 in years one to four, and €40,000 in years five to nine. Using a discount rate of 9%, the present value of the fees for a 2x28 MHz national block is approximately €245k in 2008 terms. As discussed in the main text, there has been little overall inflation between 2008 and the present.

The present cost of the fees for an individual link licence with the same channel span and duration (28 MHz and 10 years) lies between €6,295.72 and €7,554.87; the former would apply where links are not on a High Usage Path or in the Congested Frequency Band Area (lower bound) and the latter where all links are on a High Usage Path or in the Congested Frequency Band Area (upper bound). Therefore, the cost of a National Block licence is equivalent to the cost of between 33 and 39 individual link licences.

There are 25 dual polarity links where a single 28 MHz block can carry two links on both polarities – however, in the majority of cases, there is just a single link between sites.

There are a small number of links where adjacent blocks are in use. For example, an operator may operate two 28 MHz links between sites A and B using blocks P1 and P2. This effectively creates a single link with a channel spacing of 56 MHz (note that unlike national block licences, both 28 MHz links must be licenced separately). There is one four-block link, made up of blocks P1-P4 on both polarities. There are no three-block links, and eight two-block links. The overwhelming majority of links have no adjacent blocks.

Annex B Bidding incentives and the second price rule

In a simple pay-your-bid (first price) sealed bid, where there is a strong incentive to bid at less than valuation in order to reduce the price paid. Bidders choose their bid amounts to trade off the price paid if a bid wins with the probability of that bid winning. The amount by which the bid amount might be reduced below valuation will depend on each bidder's expectations about competition from other bidders: the greater the strength of competition expected, the higher the bid amount. Therefore, not only do bidders face complex decisions, but there is a risk of inefficient outcomes as who wins depends not just on relative valuations, but also on how much each bidder reduces its bid below value. In the context of a sealed bid combinatorial auction, these problems are particularly severe, as bidders are making multiple, mutually exclusive bids expressing their preferences between different packages of lots.

The simplest second price sealed bid auction is a so-called **Vickrey auction**, in which winners each pay their individual opportunity cost, as opposed to the somewhat more complex core pricing rule described above. The Vickrey auction has the property that it is optimal for a bidder to make bids for all packages of interest at bid amounts equal to its valuations, regardless of how it expects its rivals to bid.[26] This arises because a bidder's bid amount determines whether or not it wins, and which package it might win, but does not determine the amount it pays, as this is determined only by its rivals' bids, not its own. The implication is that bidders have a very simple bid strategy available – to bid at valuation – and do not need to second-guess what rivals might do.

Whilst this property of inducing truthful bidding is a theoretically attractive feature of the VIckrey auction, this approach does not tend to be often used in practice for multiple lot auctions. The simple Vickrey auction can create outcomes that might be perceived as unfair and not aligned with the outcome of a reasonable competitive process.

For example, suppose that there are three bidders (1, 2 and 3) who can bid for two lots (A and B). Suppose that bidder 1 bids 10 for lot A and bidder 2 bids 10 for lot B. Bidder 3 bids 18 for the pair AB, just

[26] Bidding at valuation is a dominant strategy in the Vickrey auction, as the pricing rule has the property that the optimal bid amount is independent of the bids expected from rivals.

losing out to the individual bidders. The opportunity cost of awarding A to bidder 1 is zero, as if we hypothetically eliminated only bidder 1 from the auction, we could not satisfy bidder 3's bid (as lot B still goes to bidder 2) and lot B would go unsold. By the same reasoning, the opportunity cost of awarding A to bidder 2 is zero. Under Vickrey pricing, bidders 1 and 2 pay nothing, even though bidder 3 is prepared to pay 18 for both lots. Bidder 3 would be an unhappy loser, as it was prepared to pay far more for the two lots than bidders 1 and 2 have paid in total.

We can also see that this difficulty with the simple Vickrey pricing approach is linked to bidder 3 having strongly synergistic valuations, to the extent that it only bid for the pair AB. If, instead, bidder 3 had bid 9 for the individual A and B lots and 18 for the pair (so there are no synergies) then bidders 1 and 2 would have faced individual opportunity costs of 9, rather than zero.

In contrast, under MRC pricing, there would be a requirement that bidders 1 and 2 jointly pay 18 in this example, which under the Vickrey-nearest sharing rule would mean each paying 9. This would ensure that bidder 3 would be happy to lose, as it would not be willing to pay more than 18 for AB. Equally bidders 1 and 2 should be happy winners, in that they each win a lot at less than their valuations. Bidders 1 and 2 are also jointly paying the least amount consistent with bidder 3 not becoming an unhappy winner.

Using MRC pricing rather than simpler Vickrey pricing has the disadvantage that it no longer provides clean incentives to bid at valuation. There may be incentives to lower bids to affect prices in cases where the Vickrey-nearest sharing rule is in operation because there are a number of bidders whose prices are determined by their joint opportunity cost (i.e. their joint opportunity cost is a binding constraint when minimising total revenue). There are two rather different cases in which this issue can arise.

First, there might be an incentive to reduce the amount bid *discretely* to lower the price paid. We can see in the example above, where bidder 1 and bidder 2 must jointly pay 18. If they each bid at valuation (i.e. 10, or indeed any amount greater than 9), then the Vickrey nearest sharing rule means they split their joint opportunity cost of 18 equally, paying 9 each. However, what if bidder 1 reduced its bid to 8? The two winners must jointly pay 18, but bidder 1 cannot pay more than its bid; therefore, bidder 1 pays 8 and bidder 2 pays 10. This a rather stark example, as to affect price, bidder 1 or 2 need to reduce their bids discretely. Clearly if both bidder 1 and bidder 2 reduce their bids to 8, then they will lose to bidder 3, so there is significant risk to bidding in this manner.

Second, there could be an incentive to reduce the amount bid *marginally* to lower the price paid. Take a somewhat different example, where:

- bidder 1 bids 10 for A and 15 for AB;

- bidder 2 bids 10 for B and 15 for AB; and
- bidder 3 bids 18 for AB.

In this case, bidder 1 wins A and bidder 2 wins B. They each face an individual opportunity cost of 5, with bidder 1's opportunity cost determined by bidder 2's incremental value of 5 for adding B to A (and vice versa). However, bidder 1 and 2 between them need to pay their joint opportunity cost of 18 determined by bidder 3's bid. The Vickrey nearest rule takes the excess of joint opportunity over the total individual opportunity costs of the winners (i.e. 8 = 18 - [5 + 5]) and splits this equally across bidder 1 and 2 to give MRC prices of 9 each.

However, suppose that bidder 1 reduces its winning bid for A by little, say to 9.9. This increases the bidder 2's individual opportunity cost to 5.1, as bidder 1 is expressing a larger incremental valuation for adding lot B than before. Because bidder 2's individual opportunity cost has increased by 0.1, application of the Vickrey nearest rule means that bidder 2's price increases by 0.05 and bidder 1's price falls by 0.05. More generally, for any small reduction in bidder 1's bid amount, it can expect its price to fall by half the reduction. By making a small reduction in its bid amount for its winning bid (and maintaining its other bids), bidder 1 gains through a lower price, but will only face a small reduction in the probability of winning. Therefore, it will benefit bidder 1 to lower its bid below valuation a little.

This second example is more relevant, as it is not necessary for a bidder to make a discrete reduction in its bid to benefit from a lower price. However, the example also assumes that bidders know a lot about the structure of bids and how prices are likely to be determined. Bidder 1 needs to know both that its joint opportunity cost with bidder 2 is relevant to determining prices and also that its winning bid will affect bidder 2's individual opportunity cost, which in turn requires knowledge that it is likely to win its single lot bid, not its bid for AB. In many practical examples, especially with more bidders and more lots, such an assessment will be difficult make.

It is possible to avoid the problem in this second example by using a different rule for resolving situations in which MRC pricing yields multiple possible prices. Rather than minimising the sum-of-squares distance from Vickrey prices, which depend on bids, a fixed reference point can be used (e.g. reserve prices).

In summary, whilst there are theoretical concerns about possible incentives to bid below valuation with MRC pricing with a Vickrey nearest sharing rule, in practice these are limited by the lack of knowledge that bidders are likely to have about which bids will be relevant in determining prices. Therefore, it is reasonable to expect bidders to take bidding at value as reasonable starting point, which it will typically be difficult to improve upon. In turn, if bidders adopt this bidding strategy it follows that a second price sealed bid with MRC pricing is likely to yield largely efficient outcomes.

Annex C International awards

6.1.1 Australia

Australia auctioned Local Multipoint Distribution Services (28 GHz and 31 GHz) spectrum with a simultaneous multiple round auction (SMRA) in 1999. One bidder (AAPT) won all the lots for AUD 66.2m – the highest bids were AUD 35.7m for Sydney and AUD 22.7m for Melbourne.

Australia auctioned BWA 27GHz Auction in 2000 also using a SMRA. The auctioned ended after 3 bidding rounds at a total of AUD 37.603m. 65 of the 126 lots available were sold.

6.1.2 Austria

Austria auctioned regional WLL spectrum in 2001 using an SMRA. Of the 30 licences available, only 9 were sold.

In 2007, Austria auctioned off 2x84 MHz of spectrum to a single bidder (One GmbH, now Orange Austria). Of the 21 packages available, only three were sold.

6.1.3 Canada

Canada auctioned 24 GHz and 38 GHz spectrum in 1999. Of the 354 licences made available for the auction, 260 were awarded to 12 licensees. The frequency band structure was consistent with that of the United States.

The 24 GHz band was intended for either point-to-point or point-to-multipoint systems. Some 38 GHz blocks were reserved for point-to-point only; the remainder could be used for point-to-point or point-to-multipoint.

6.1.4 Italy

In Italy, the 2002 auction of regional WLL licences in the 26 and 28 GHz bands raised a total EUR40 million, averaging EUR0.56 million per regional licence, and only one region saw competitive bids. In only region, Umbria, was all the available spectrum awarded.

6.1.5 United Kingdom

The United Kingdom auctioned regional 28 GHz licences for broadband fixed wireless access in 2000. Of the 42 licences on offer, only 15 were awarded; of the fourteen regions, all licences were only sold in only three of them. The auction raised £38.2m (an average of £2.5m per licence). The remaining 28 GHz frequencies in the UK were successfully auctioned in 2008.

In 2008 the UK auctioned 10 GHz, 26 GHz, 32 GHz and 40 GHz spectrum in a combinatorial clock auction. 26 GHz, 32 GHz and 40 GHz licences were technology and application neutral, and with the exception of three 28 GHz lots, were national licences. 10 GHz licences were restricted to fixed systems and wireless cameras.

The auction was only weakly competitive – all bidders were successfully in winning spectrum and revenues were less than a tenth of values.

6.1.6 United States

The FCC auctioned and re-auctioned Local Multipoint Distribution Systems licences in 1998 and 1998 (Auctions 17 and 23). LMDS licences are in the 28 GHz and 31 GHz bands

24 GHz spectrum was auctioned in 2004 (FCC Auction 56). 880 licences of 2x80 MHz were offered in 176 regions, however only seven licences were sold.

6.1.7 Norway

Norway auctioned 23 GHz national licences in 2008 using a sealed-bid, first-price auction where three frequency blocks were auctioned off. Tele2 Norge AS won all three frequency blocks. Additionally one bid was rejected due to lack of documentation and another bid was rejected because it was not received within the deadline.

Norway planned to auction national licences for spectrum in the 23 GHz, 28 GHz, 32 GHz and 38 GHz bands in 2013. However as only two companies (TeliaSonera and Mobile Norway) registered for the auction and there was excess supply, spectrum was awarded by agreement rather than by auction[27]. 140 MHz of 23 GHz, 112 MHz of

[27] NKOM, Auction # 17 (23, 28, 32 and 38 GHz) https://eng.nkom.no/technical/frequency-auctions/auctions/planned-completed-auctions/auction-17-23-28-32-and-38-ghz

28 GHz and 392 MHz of 32 GHz spectrum were awarded for a total of 3,050,000 NOK.

6.1.8 Sweden

Sweden sold national 28 GHz licences in 2009 using a clock auction conducted via encrypted email. All 18 licences were sold in the first round for SEK 900,000 to three bidders. The licences are service-neutral and (with certain restrictions) technology-neutral.

Annex D Example bidding

In this annex we give simple examples of making bids under Option A and Option B auction designs.

Both auction designs use an opportunity cost rule for pricing the assigned lots. The implication of this is that bidders are likely to find making bids for different packages of lots at their valuation an effective strategy. Although this straightforward bidding strategy may not necessarily be optimal, bidders are unlikely to be able to improve on it significantly in practice given uncertainty about how rival bidders might bid.

Somewhat different considerations apply to any bidder who is budget constrained and not able to make all of its bids straightforwardly at value. We do not consider this possibility as particularly likely given the likely level of bid amounts for this auction. However, were a bidder to face such a budget constraint it would need to assess its likelihood of winning different numbers of lots and make adjustments to its bid strategy accordingly (see Section 5.1.4).

Therefore, we make the simplifying assumption of straightforward bidding when demonstrating how a bidder might reflect its objectives in a set of bids. This should not be taken as a recommendation to adopt any particular bidding strategy.

Bidding under Option A

The Option A auction design is a sealed bid combinatorial auction with frequency generic lots; this approach is recommended if frequency preferences are not material (see Section 5.3). Under Option A, the auction, like the 2008 auction, would have two stages:

- a main stage; and
- an assignment stage.

In the main stage bidders need to bid to reflect their preferences for the number of lots they wish to win, whilst in the assignment stage bidders need to bid to reflect their preferences for the frequencies assigned to any lots won in the first stage.

If a bidder does not have significant preferences across frequencies, the bidder can simply bid at value for the number of lots they are interested in. Multiple bids can be made for different numbers of lots. These multiple bids are all submitted simultaneously.

For example, suppose that a bidder is interested in 2, 3 or 4 blocks of 2x28 MHz. Suppose that it has valuations of, say, €1m for 2 lots, €2m for 3 lots and €2.5m for 4 lots. It would then simply make three bids for each number of lots at its respective valuation (given the maintained assumption of straightforward bidding). There is no risk of the bidder winning a single block, as it has not made a bid for a single lot.

With no frequency preference, the bidder could simply make zero bids for all frequency options in the assignment stage (assuming it won some lots in the main stage).

Where a bidder has frequency preferences, bidding can become complicated under Option A, as determining how much to bid in the main stage requires some expectation to be formed of how likely the bidder is to win its preferred option for frequencies in the assignment stage. For example, suppose that a bidder had a similar valuation structure to before (with values of €1m for 2 blocks, €2m for 3 blocks, €2.5m for 4 blocks), but that in each case these valuations would be boosted by 10% if the bidder were assigned certain specific frequencies. (We do not need to consider the details of which specific frequencies these might be.)

If the bidder expected that other winners of lots in the main stage would not have any significant preference for particular frequencies, then the bidder could anticipate being assigned its preferred frequencies in the assignment stage. Moreover, the additional price set in the assignment stage would be zero, assuming that other bidders did not express any frequency preferences. Therefore, given these expectations about the assignment stage, the bidder would be prepared to bid €1.1m for 2 lots, €2.2m for 3 blocks and €2.75m for 4 blocks in the main stage.

Now suppose instead that the bidder expected to have to compete with other winner in the assignment stage for its preferred frequency assignment. In this case the bidder would expect to either not win its frequency preferred option (with some probability) or else to win its preferred frequency option (with some probability) and pay a non-zero price. Therefore, the bidder will not be prepared to bid as much in the main stage. It would bid some amount intermediate between €1m and €1.1m for 2 lots, some amount intermediate between €2m and €2.2m for 3 lots and some amount intermediate between €2.5m and €2.75m for 4 lots. The exact amount bid in the main stage would depend on the bidder's expectations of what exact would happy in the main stage.

Suppose that the bidder won, say, 2 lots in the main stage. Then, regardless of what it had bid in the main stage, it would bid €0.1m for its preferred frequency option in the assignment stage and zero for all the other options.

Bidding under Option B

Option B is a sealed bid combinatorial auction using similar rules, but with frequency-specific lots. Option B is recommended if some bidders are likely to have strong preferences across frequencies (sufficient to affect the value of one or more blocks materially depending on which frequencies they are allocated). Unlike Option A, there would be just a single stage of bidding.

Bids would be made for contiguous ranges of (duplex) frequencies within the proposed auction cap. Bidders would need to specify their willingness to pay for the differing numbers of lots at each potential position in the band. As we have discussed, bidding for various packages is logistically not too difficult as there are 85 distinct packages (varying by number of blocks within the auction cap of 5 blocks and frequency allocations), not all of which are likely to be of interest.

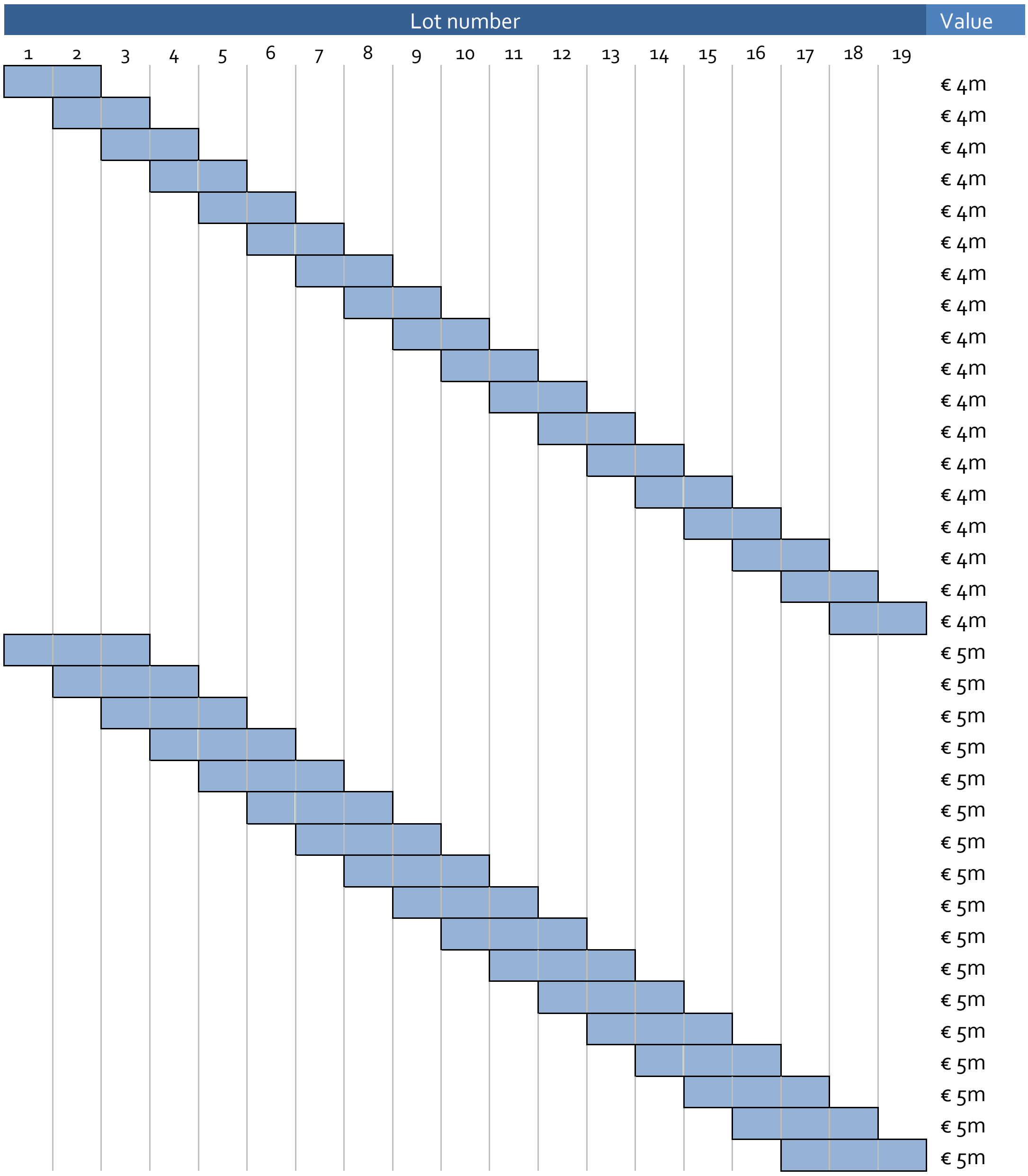
Example One: flexible demand, no frequency preferences

Suppose Bidder A is a new entrant; they have no existing holdings or deployed infrastructure. Bidder A also has significantly flexible demand. Bidder A is happy to obtain 2 or 3 lots but has no preference regarding their position in the band. Based on Bidder A's valuations they are willing to bid €4m for 2 lots and €5m for 3 lots.

In Option A, Bidder A would simply bid for 2 and 3 lots at those values respectively and then submit zero bids during the assignment stage regardless of the outcome of the allocation stage.

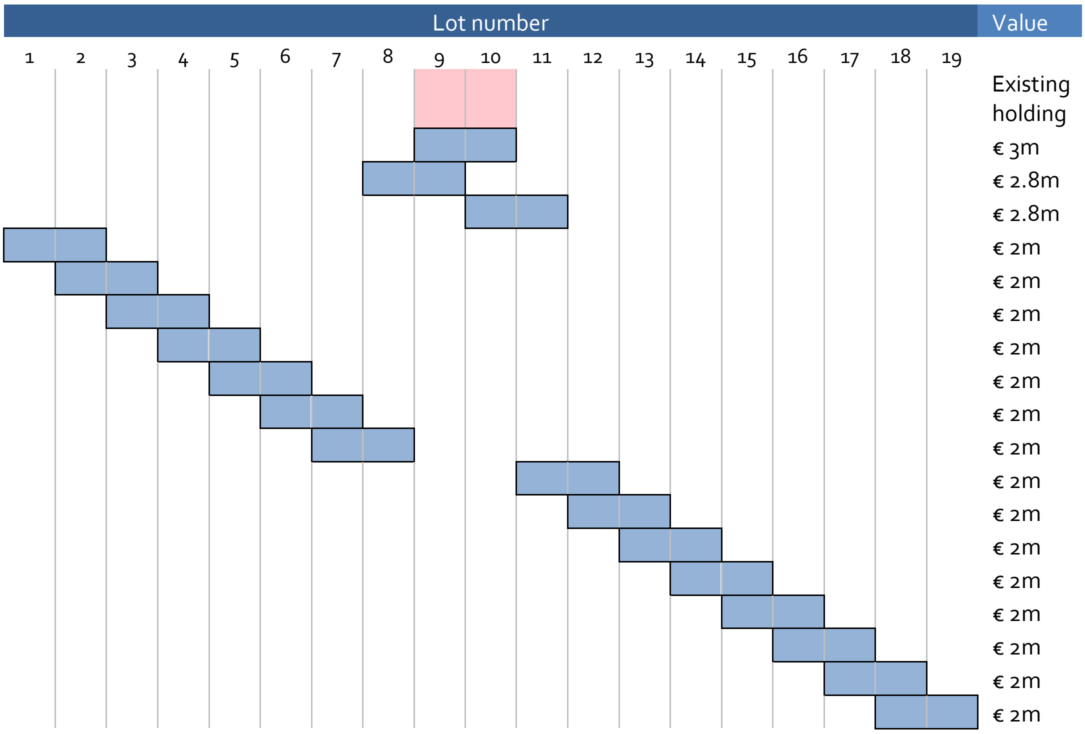
Under Option B, Bidder A could bid their valuation for two or three lots across all possible frequency allocations of those lots. The set of bids is represented graphically below. There are 18 possible frequency assignments for a two blocks and 17 possible assignments for three blocks.

In practice, it would be possible to allow a bidder to make these bids more succinctly through a bidding form. For example, the bid form could provide an option to bid for all packages with N blocks (regardless of frequency) at a common price. This would allow the 18 bids for two blocks to be summarised by a single implicit bid for all frequency options (and similarly the 17 bids for three blocks summarised into a single bid).



Example two: inflexible demand, frequency preferences

Suppose Bidder B has an existing holding of two blocks in the band. The bidder has no intention to purchase any further lots and does not want just one lot. Bidder B is only interested in two lots. The bidder wants to avoid retuning costs and values their existing frequencies. There are minor retuning costs if the bidder's assignment moves one block (i.e. 28 MHz) up or down from its existing frequency assignment, but larger costs if he bidder moves further. Based on their value for the various frequency assignments they might bid as follows.



If we had used Option A with frequency generic lots, then the bidder could submit a single bid for two lots in the allocation stage at between €3m and €2m depending on its expectations for the assignment stage. If the bidder wins two lots, in the assignment stage the bidder could bid their *incremental* valuation arising from avoiding retuning costs. This would involve the following non-zero bids (with all other frequency options bid at zero):