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3.4-3.8 GHz Award Procedure: Options for Product and Auction Design

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Content

1 Overview

This document discusses the product and auction design options for the awarding of frequencies in Austria in the 3.4-3.8 GHz range.

Both product design and auction design are crucial for determining whether an award procedure is suitable for fulfilling the award goals (as detailed in Chapter 2 of the consultation document). So product and auction design are closely related and must be analysed together.

For example, to ensure the efficient assigning and use of frequencies it may be advisable to award the available frequencies in blocks which are 'small' compared with the frequency spectrum generally required by the successful bidders. Such a packaging system gives the bidders the flexibility to acquire the best portfolio of frequencies for them. Dividing the available spectrum among bidders thus meets their needs, as opposed to being prescribed by the auctioneer. Such packaging does expose bidders to aggregation risks though, which must be cushioned by the auction design. The same applies to awarding frequencies at regional level. Packaging in this way means regional providers can bid for frequencies. However, bidders that follow trans-regional or national business models are exposed to the risk of acquiring frequencies in a subset of regions that may only be of limited use for them.

Here, product design plays the more important role. Dividing the available frequencies into lots that are bid for during the auction should primarily accommodate the needs of the potential users, while offering the largest possible scope for the different types of user to bid for the spectrum on an equal footing. This is the only way to determine during the auction how the frequencies can best be used in terms of purpose and provider. However, where the auction design is unable to address the uncertainties and risks adequately enough, or where the additional complexity bears no relation to the advantages of greater flexibility, some compromises should be made with the product design.

Figure 1 shows the implications of the award goals for the product and auction design.

Figure 1: Award goals and implications for product and auction design

Award goal	Implications for product and auction design
Legal certainty	Transparency of procedure Best possible control of bidders over auction result relevant for them (awarded bid, price payable) Comprehensibility of auction design to minimise risk of bidding errors
Ensure efficient assignment and utilisation of frequencies	Flexibility with regard to frequency packages and frequency utilisation; technology and service neutrality Avoidance/mitigation of aggregation and substitution risks Allocation of contiguous frequencies (and identical across regional borders) where possible Minimise risk of inefficient and unsold lots
Ensure/encourage effective competition	Appropriate caps
Innovation	See "efficient assignment and utilisation of frequencies"
Greater connectivity and expanded coverage	Appropriate coverage requirements No disadvantage for regional broadband providers

2 Product design

2.1 Basic information

Initial thoughts on product design – i.e. dividing the available spectrum into lots that are then bid for during the auction – are based on the potential use of the available frequencies.

2.1.1 Available spectrum

A total of 390 MHz are available in the 3410-3800 MHz range. While this spectrum is a contiguous frequency block, it should nevertheless not be considered homogeneous. The frequency range comprises the two separate LTE bands 42 (3400-3600 MHz) and 43 (3600-3800 MHz). These bands should be considered separately because:

- aggregating frequencies for one carrier across band limits means losses of efficiency (especially for 5G carriers with a channel width of 100 MHz);
- for some users (specifically regional broadband providers) band 43 offers no real alternative to frequencies in band 42;
- the two bands differ in terms of their availability dates for the frequencies; and
- different equipment is required, at least just now, to utilise the frequencies in the two bands.

Consequently, the frequencies available are:

- 190 MHz in band 42; and
- 200 MHz in band 43.

2.1.2 Potential users

Potential users include mobile network operators, regional broadband providers and power suppliers.

- Mobile network operators would use the spectrum for mobile data services using TDD LTE or 5G (New Radio) technology. TDD LTE is based on channel widths of 5, 10, 15 or 20 MHz – that said, mobile service providers are generally interested in aggregating channels of up to around 100 MHz to be able to offer their clients top data transmission rates. 5G New Radio is based on channel widths of 100 MHz (these channels can also be used in part). Mobile network operators particularly have a need for this capacity spectrum in densely populated areas,

  and less so in rural areas – but they are also interested in acquiring frequencies at national level, and minimising regional differences in the assigned spectra where applicable. Mobile network operators have a greater interest in an asymmetric download/upload ratio.
- Broadband providers require multiples of 10 or 20 MHz, and during consultations indicated a minimum spectrum requirement of 80-160 MHz. With a few exceptions, these users are interested in individual regions (defined accordingly). Some operators can only use frequencies in band 42. Broadband providers that want to focus on serving business customers are interested in a symmetric download/upload ratio.

Demand for frequencies is as follows based on the Consultation on Future Frequency Awards and industry talks:

Potential users are mostly interested in being assigned a spectrum of 100-200 MHz; one user would like to acquire up to 260 MHz. Demand per band is not substantially different from the demand for both bands together, which suggests that most users consider the two bands as substitutes. In spite of the aggregation advantages though, it cannot be ruled out that bidders will want to acquire frequencies in both bands under certain circumstances. The majority of potential users earmark a minimum spectrum requirement of 60-100 MHz, which is necessary for the efficient deployment of frequencies. Some users indicate that they could also use a smaller range (for internal purposes for example), and the results of the recent 3.6 GHz auction in Ireland suggest that assigning smaller frequency spectra can in fact be attractive for bidders.

2.2 Product design parameters

2.2.1 Generic or frequency-specific blocks

The effective use of frequencies requires the assignment of contiguous frequency blocks. Such an assignment is facilitated by initially offering the available spectrum in the form of generic blocks and then in a second step assigning specific frequencies to the winners of spectra. Given the differences between the two bands, however, it should be clarified from the beginning which band a bidder is acquiring frequencies in. This means there must be two categories of generic block which the bidders can bid for.

2.2.2 Lot size

The need identified by the potential users is largely the same but does allow for significant flexibility with regard to the frequency spectrum targeted. Accordingly, the efficient assignment of frequencies and the efficient use of frequencies afterwards require that the product design allows competition for incremental spectrum. This is supported by dividing the available spectrum into lots, which are small compared to the typical minimum spectrum requirement identified by potential users.

Based on the potential channel widths for LTE, this means the lots can be 5 MHz, 10 MHz, 15 MHz and 20 MHz. In the consultation and during the industry talks, lot sizes of 10 or 20 MHz were considered appropriate (with a certain preference for lots of 10 MHz).

The benefit with lots of 10 MHz is that the frequency package available in band 42 is a multiple of 10 MHz, but not of 20 MHz. What is more, a lot size of 10 MHz can be better under certain circumstances, if bidders who do not wish to operate synchronous networks want to buy additional frequencies in order to avoid interferences with neighbouring users. By comparison, 20 MHz lots have the advantage that the individual lot size is identical to the maximum channel width for LTE, and so in all likelihood there will be no synergistic valuation within the possible increments, which reduces the aggregation risks (more details below). Larger lots reduce flexibility, but also complexity, because there are fewer potential combinations and auction results.

As a result, we are principally talking about lot sizes of 10 MHz or 20 MHz. The decision can be adapted in line with the respective auction design.

2.2.3 Regional structure

Regional broadband providers are potential users of the frequencies to be awarded. Such providers currently use frequencies in band 42 at more than 450 broadcasting locations, and supply approximately 11,000 subscribers.

To give these providers and the potential new entrants the opportunity to bid effectively for the spectrum available, creating a regional structure is advisable. As shown by the recent auction of frequencies in these bands in Ireland, regionally differentiated use by regional broadband providers coupled with a variation of the frequency packages used by mobile network operators is a realistic result of a competitive award procedure.

The following regional structures are currently up for consideration:

- awarding at level of federal states, with Vienna and Lower Austria constituting one region (i.e. eight regions in total);
- awarding at level of nine federal states, but Linz and Graz kept separate, i.e. eleven regions in total;

- a flexible regional structure of four groups of federal states, keeping the federal capitals separate (and other larger cities where applicable), i.e. eight regions in total.

Should it transpire in the course of the consultation that the interest in a regional award process is very limited, or if there are other reasons arguing against a regional award, then awarding at national level is also possible of course.

In light of the complexity involved, having more than eleven regions can essentially be ruled out based on current considerations.

2.2.4 Limitations on use

During the Consultation on Future Frequency Awards and industry talks it emerged that there are various requirements for the download/upload ratio, and mobile network operators as well as some broadband providers are interested in a rather asymmetric ratio (e.g. 3:1), while others favour a symmetric ratio (e.g. 1:1).

Operating networks with different download/upload ratios rule out synchronous use. This is why there needs to be a guard band where different users meet.

The purpose of the product design should be to allow various uses, while at the same time minimising the potentially unusable bandwidth created as a result.

In principle the following options are conceivable:

- The regulatory authority defines a standard ratio for downloading and uploading. Network operators that want to use their networks with different download/upload ratios are responsible for avoiding interferences, and are therefore unable to use the entire bandwidth they have acquired. The solution disadvantages bidders that are interested in alternative download/upload ratios because they either have to adapt to the standard use or under certain circumstances are unable to effectively use part of the frequencies they have acquired: the number of frequencies effectively available depends on the assignment of specific frequencies, which results in who the neighbours in the band are. Even if bands are planned in such a way that there is only one border between different types of user, all non-standard users are exposed to the risk of being unable to use part of their frequencies, and therefore may have to bid for more spectrum than they would actually need if they had no standard users as neighbours in the band.[1]

- Alternatively, the regulatory authority can define two standard ratios for downloading and uploading, which accommodate the different needs in the best way possible (standard use 1 – asymmetric, standard use 2 – symmetric). Assigning specific frequencies to the successful bidders is then designed in such a manner that users of the same type are placed beside each other in the band, meaning that there is essentially only one border where different user types meet. This minimises the need for frequencies that are effectively unused and function as guard blocks (see Box 1). A block used as a guard block can either be retained flexibly (i.e. the frequency package available is adjusted depending on whether different users bid in the same band or not), or is awarded to one of the winners of frequencies in the assignment stage (and actually used by this winner if there is no need for a guard block).[2]

Both options enable network operators that pursue different business models to bid for the available frequencies on a more even basis.

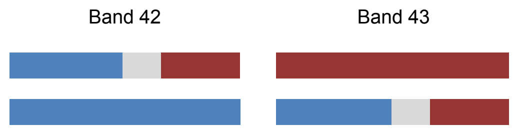
[1] Uncertainty about whether a non-standard user has a standard user for a band neighbour is naturally minimal if there is most probably only one non-standard user in every band.

[2] If a block is retained and awarded to one of the winners in the assignment stage, then bidders bid in the assignment stage for additional spectrum if the block does not have to be used as a guard block.

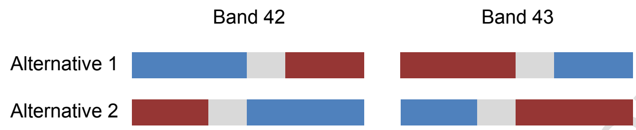
Box 1: Minimising effectively unusable frequencies with different user requirements

Define two user types with different DL/UL requirements – standard user 1, asymmetric, e.g. 3:1, and standard user 2, symmetric, e.g. 1:1.

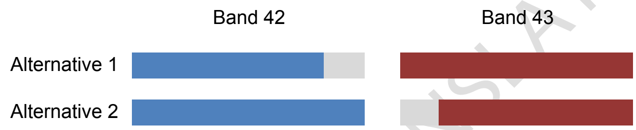
When allocating specific frequencies, users of the same type are positioned beside each other, which means there can be only one border between different user types, and only one guard block per band is required if there are different winners.



User types within the two bands can be positioned in such a way that the same user types meet at the band limit.



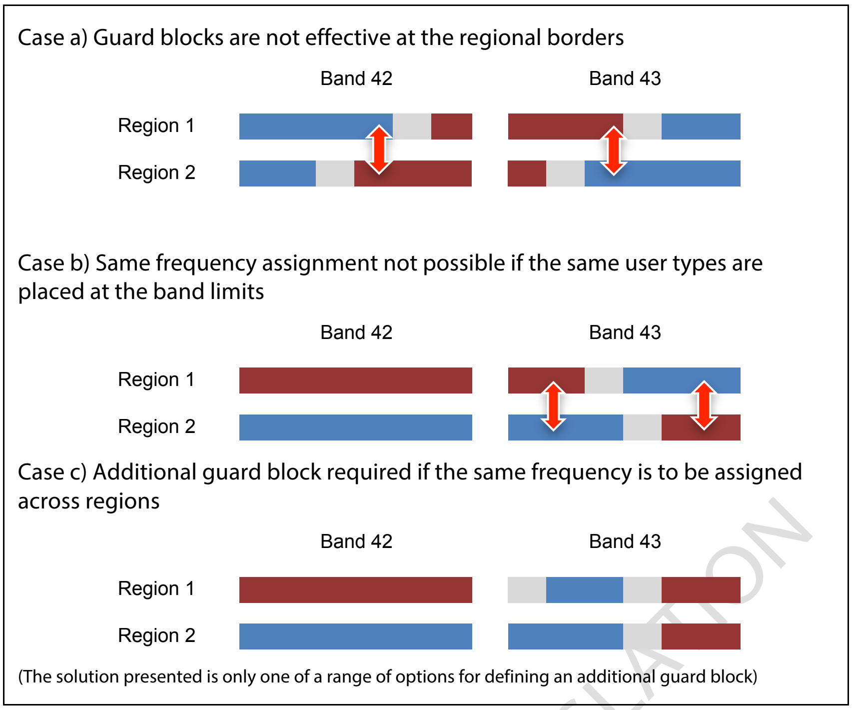
If there are only winners of the same type within a band, but the uses in the two bands differ, there must be a guard block between the bands.



However, such a solution is complicated by the awarding of frequencies at regional level:

- Firstly, the division between the user types can differ by region. In this case, the guard blocks at the regional borders are not effective (Figure 2 – case a).
- Secondly, it can happen that only one user type wins in one band, but this is not the same for every region. In this case it is either impossible to assign the same frequencies across regional borders (Figure 2 – case b), or additional guard blocks have to be provided (Figure 2, case c).

Figure 2: Potential complications with regional frequency awards and different user types



The first problem can only be solved by adding an additional restriction that frequencies must be assigned in the same way to the different user types across all regions. This can happen either ex ante by distributing the bands among the different user types, or during the auction itself by limiting the permitted outcomes to those where the distribution across regions is identical. Regardless of how distribution takes place, the explicit restriction to having an identical distribution across regions conflicts with the goal of an efficient use of frequencies.

For this reason, the following solution is preferable: At the regional borders, the field strength limits applicable at the national borders to avoid interference must be complied with. If standard users of the same type come together, synchronous operations with higher field strengths – to be agreed under private law – are possible.

The second problem can be solved with some auction formats:

- all conceivable scenarios with regard to the number and position of guard blocks are defined;
- the optimal result is determined for each scenario (i.e. combining bids with the maximum value that can be satisfied with what is offered in the given scenario);
- the best result is identified across all scenarios, where solutions are ignored in which the number of guard blocks required is greater than the number assumed in the scenario.

Such a 'supply scenario' approach, however, is difficult to implement in practice given the number of potential scenarios.

This is why the following solution is preferable:

- One standard use is defined for one band, while two different standard uses are possible for the other band.
- If different user types win in this band, they are separated into two groups and positioned so that the user group on the band limit is the same as the standard use in the other band.
- The two user groups are separated by a guard block.
- The guard block can either be retained (and awarded to a winner in the assignment stage if it is not required), or made available flexibly during the auction.

Given the need expressed in the Consultation on Future Frequency Awards and industry talks, it seems reasonable to plan for one standard use with an asymmetric download/upload ratio for band 43 (standard use 1). The practical restriction that this brings should be minimal; only bidders for whom symmetric use in band 43 is an option are affected.

3 Auction design

3.1 Basic information

The following should be assumed for the auction design:

- both bands are to be considered separately;
- frequencies will be awarded at national or regional level, in which case a regional structure may comprise eight, nine or eleven regions;
- spectrum awarded in 10 MHz or 20 MHz blocks;
- in the run-up to the procedure (for example when applying for admission) bidders in band 42 may state their preference for one of two standard uses (with regard to the download/upload ratio).

The auction procedure should generally be conducted in two stages, whereby the first stage would determine the bidders that would receive certain amounts of spectrum within specified bands and in specified regions (principal stage), while the specific frequencies would then be assigned to spectrum winners in the second stage (assignment stage).

In the award stage, bidders can express their preferences for various frequency spectra in the respective bands and in the given regions.

The procedure selected for the award stage should eliminate aggregation risks for bidders as much as possible, but also ensure that frequencies which are of value to bidders do not remain unsold. The procedure should enable bidders to transfer their demand freely from one band to the other, and generally impose no restrictions on changing between lot categories. At the same time it should minimise complexity and uncertainty for bidders, which means that:

- ideally there are no complex pricing rules, and successful bidders simply pay the amount of their winning bid;
- bidders have the opportunity to react to changing prices and demand and are exposed to no risk of possibly ending the auction empty-handed if they have not explicitly accepted this outcome.

The formats listed below generally come under consideration for the principal stage:

- Simultaneous multi-round auction (potentially in a hybrid form involving the use of elements from the clock auction to speed up auction progress)
- Simple clock auction
- ‘Clock plus’ variants, i.e. employing various bid restrictions to reduce the risk of unsold lots

- Clock auction with 'clinching', format proposed by H3A in which lots are awarded early on in the auction process
- Combinatorial clock auction (CCA)
- Combinatorial multi-round auction (CMRA), first used in the 1800 MHz auction in Denmark

The pros and cons of the different formats are elaborated in more detail below.

The assignment stage guarantees that contiguous spectrum is assigned within each band and in each region, while furthermore ensuring the number of potentially unusable frequencies is minimised and bidders are assigned the same frequencies across regions whenever possible. In principle, the assignment of specific frequencies can be entrusted to negotiations among the winners based on the assignment options proposed by the regulatory authority. Given the complexity of such negotiations and the likelihood of no agreement being reached on the assignments within a reasonable timeframe, a separate bidding process where the frequency winners state their preferences for potential assignment options is likely to be the more effective solution. A sealed bidding procedure with prices based on opportunity costs is suitable for this bidding process.

3.2 Evaluation of potential auction formats for the award stage

3.2.1 Simultaneous multi-round auction (SMRA)

Description

This auction format was developed for the auction of PCS frequencies in the United States in 1994, and has since been deployed in many frequency award procedures (including in Austria on several occasions, starting with the UMTS auction in 2000 and ending with the award of the 3.5 GHz frequencies in 2009).

The detailed auction rules vary from auction to auction. But what is common to all simultaneous multi-round auctions is that:

- bidders bid for individual lots in each round;
- at the end of a round the auctioneer determines the provisional winning bid for each lot from all the bids submitted for these lots; these provisional winning bids are binding, which means the bidders may not withdraw them (certain exceptions aside);
- a new round is held in which bidders can make new bids under the rules of activity; these new bids must be higher than the

provisional winning bids (and higher than the minimum bid for lots yet to receive any bids); and
- the procedure ends after a round where no new bids were made (and bidders took none of the actions specified in the auction rules). At this point, the lots are awarded to the bidders holding the provisional winning bids. The winners pay the amount of their provisional winning bids.

The core element of the simultaneous multi-round auction is the rules of activity, which determine the bidding options for the individual bidders in each round. The individual lots are generally allocated bidding points, designed to measure the activity of a bidder.

- The activity of a bidder in one round is generally the sum of the bidding points of the lots for which the bidder holds the provisional winning bids at the start of the round, and for which the bidder makes new bids during the round, minus the sum of the bidding points of the lots for which the bidder withdraws his provisional winning bids during the round (provided such withdrawals are permitted).
- The activity of a bidder in each round may not exceed the maximum permitted level for the bidder (the bidder's 'bidding eligibility').
- The bidder's activity in a round determines the bidding eligibility for the bidder in the next round.

The rules of activity ensure that a bidder may not increase demand (measured in bidding points) as prices increase during the auction.[3]

Pros and cons

This format is a tried-and-tested and established design that is relatively easy for bidders to understand and has been deployed successfully in many cases.

However, the format does have some known drawbacks, especially with regard to switching between combinations of lots and the risk of acquiring unwanted combinations or subsets of lots.

During a simultaneous multi-round auction, bidders can decide which lots to bid for, but they are bound by their provisional winning bids.

The binding nature of the provisional winning bids means that bidders may not be in a position to switch from one combination of lots to another in one step. If the procedure ends before such a

[3] This does not apply for variable activity requirements as long as the activity requirement is below 100%.

change can be completed, bidders may win a combination of lots that they do not want.

The binding nature of the provisional winning bids also means that bidders may only win subsets of the lots (or regions) required, which are useless for them, or worth less in such a combination than the bidders have to pay.

If individual lots are complementary (i.e. if the value of a combination of lots exceeds the sum of the values of the individual lots), then both of these problems may potentially lead to inefficiency and expose bidders to the risk of purchasing lots at a loss in the auction.

Such complementarities stem primarily from the regional award of frequencies for bidders that want to acquire the spectrum at national level or in several regions (e.g. in all rural regions). To a lesser extent, complementarities also stem from the fact that larger frequency spectra enable a greater spectral efficiency (the minimum bandwidth from which point onwards the incremental value of additional frequencies decreases is potentially relatively small, and given the size of the available spectrum it should be possible for every successful bidder to acquire this minimum bandwidth). Having said that, problems do arise when switching between bands (see Box 2).

Box 2: Limited switching opportunities in simultaneous multi-round auction

Let us assume a bidder is interested in acquiring 100 MHz. The bidder has a mild preference for spectrum in band 42 but is willing to switch to band 43 if the price difference between the two bands is greater than x €/MHz. Yet it is important for the bidder that the entire spectrum is assigned within the same band (because it is to be used for 5G New Radio for example).

Let us assume the bidder starts bidding in band 42, that the demand in this band is greater than in band 43, and therefore the prices increase and the price gap grows.

As the prices in band 42 reach an amount x €/MHz above the prices in band 43, the bidder holds provisional winning bids for 40 MHz. Bids for the remaining 60 MHz are not considered provisional winning bids by the auctioneer.

This means the bidder can switch to band 43 with half of his demand. By doing so it runs the risk of potentially having 40 MHz in one band and 60 MHz in another band, instead of winning the required 100 MHz in one band. The risk of not being outbid for the provisional winning bids is comparatively large when the excess demand in band 42 is not much greater than 40 MHz and accordingly, switching to the other band can practically be ruled out.

Another problem of the simultaneous multi-round auction is that bidders potentially have an incentive to reduce their demand early to benefit from lower prices. This can mean that bidders win spectrum with a valuation below that which the frequencies would carry for other bidders.

Yet in this context we should note that the incentives for a bidder to reduce demand early increase the more lots the given bidder would like to acquire. Consequently, when the incentive to reduce demand early leads to an inefficient outcome, the stronger bidders win a smaller spectrum than would otherwise be the case with an efficient outcome. This loss of efficiency is countered with the advantage of a more even spectrum assignment, which in turn can be conducive to competition on downstream markets. At any rate, the incentive for reducing demand early can be lowered by setting higher minimum prices and limiting the transparency of the procedure where applicable.

One problem with implementing simultaneous multi-round auctions in practice is that if there are several identical lots, a large number of rounds can be required to ensure the prices of all lots increase. This is reflected in the fact that this auction format needs many rounds to eliminate the surplus demand.

Evaluation

Given the limited switching opportunities and the aggregation risk that national bidders in particular are exposed to, simultaneous multi-round auctions are not suitable for the regional award of frequencies because in all likelihood they will not result in an efficient assignment of frequencies. Should the spectrum be awarded at national level, this format is definitely an option though.

If a simultaneous multi-round auction is selected, however, a hybrid version should be preferred, where, similarly to the auction planned in the UK for the award of frequencies in the 2.3 and 3.4 GHz bands,[4] the bidders do not bid for individual lots but instead specify the quantity requested in the given band at a price per block. The auctioneer then determines the provisional winning bids by randomly sorting the bidders who bid for lots in the given band, and defines the bids submitted by the bidders as provisional winning bids until what is offered in the band is assigned, or all bids have been accepted (in this case, bids possibly submitted earlier that were identified as the highest provisional bids are upheld as the provisional winning bids at a lower price). This means that for each band there can be no more than one bidder whose demand was not fully satisfied. The price goes up for a band in which all provisional winning bids are submitted at the round price; otherwise it remains unchanged.

The advantage of this procedure is that the price of all lots within a band goes up in the event of excess demand, and there is no need for further rounds to bring about such a price increase.

[4] For details see https://www.ofcom.org.uk/consultations-and-statements/category-1/2.3-3.4-ghz-auction-design

As in the UK, rules on withdrawing bids or minimum bandwidth requirements may also be applied, though the legal permissibility of withdrawing provisional winning bids in Austria does require clarification in our view.

Two objectives have to be weighed up with regard to information policy. Firstly, bidders must receive sufficient information so they can make effective bidding decisions. Secondly, the information policy should hinder strategic bidding. The solution proposed by Ofcom in the UK to inform bidders about the excess demand after each round in broad categories (e.g. 'more than 60 MHz' 'more than 120 MHz', etc.) seems to be a reasonable compromise in this respect.

3.2.2 Simple clock auction

Description

Similar to the simultaneous multi-round auction, in a simple clock auction bidders bid for lots in several rounds, but the lots are in various categories. For each category the auctioneer sets a clock price, and the bidders specify the quantity requested in the individual categories at this price.

The auctioneer then aggregates the demand expressed by the individual bidders. Should this aggregate demand exceed what is offered in at least one category, the auctioneer raises the clock price for this category and another round takes place.

Bidders that reduce their demand in a lot category can generally specify prices between the clock price of the previous round and the prevailing clock price, up to which level they want to maintain their specified demand. Such exit bids ensure there is no sudden excess of supply because the auctioneer set the clock price too high.

The auction ends after a round in which there was no excess demand in any category.

Just like with simultaneous multi-round auctions, the rules of activity ensure that bidders are unable to raise their demand in view of rising prices. Generally, the same system of bidding points, bidding eligibility and activity levels is used.

Pros and cons

As with simultaneous multi-round auctions, the clock auction is a relatively simple procedure, both in terms of implementation and with regard to transparency for bidders.

In contrast to the simultaneous multi-round auction there are no provisional winning bids in the clock auction. This means there are no limitations on switching between lot categories either, nor any risk that bidders win subsets of lots that they do not want.

Conversely, however, there is a risk that inefficient and unsold lots remain which could be assigned in a simultaneous multi-round auction – albeit at the expense of the bidder, who pays more for the lots than their subjective value (see example in Box 3).

The potential inefficiency of the outcome can be reduced by means of a follow-up process, in which any unsold lots are offered, but not completely resolved – not least because lots can be assigned inefficiently in the main process. What is more, such a follow-up process can influence bidding behaviour in the main auction. If bidders speculate about acquiring unsold lots more cost-effectively, this itself can raise the likelihood of lots remaining unsold.

Box 3: Inefficient and unsold lots – comparison between clock auction and simultaneous multi-round auction

Let us assume there are two bidders, A and B, who bid for three lots.

The valuations of the bidders for one and two lots are as follows:

	1 lot	2 lots
A	3	10
B	8	16

In a clock auction, bidder B bids for two lots up to a price of 8, and then reduces the demand to zero. Bidder A would bid for two lots up to a price of 5, and exit completely at any higher price. The auction ends with a price of 5, at which B acquires two lots and A none at all. One lot remains unsold, although bidder A is willing to pay 3. This problem cannot be resolved with conventional exit bids because they must be higher than the clock price in the previous round.

If A expects he can win two lots, he will also bid for two lots in a simultaneous multi-round auction, as long as the average price per lot is less than 5. If the average price rises above 5, however, the bidder cannot simply stop bidding: he holds a provisional winning bid for at least one lot.

Bidder A actually has an incentive to keep bidding for two lots as long as he expects to win them both as long as the average price per lot rises to 7, because for every lower average price p, the loss if he wins one lot (3 – p) is greater than the loss if he wins two lots (10 – 2p). The simultaneous multi-round auction ends with A holding a provisional winning bid for one lot, and B winning two lots. Here the result is efficient – albeit with A paying more than the lot is worth to him.[5]

Furthermore, lots can remain unsold because with several lot categories the rules of activity prevent bidders from bidding for all the lots they are interested in. Let us assume there are two categories (e.g. two bands) X and Y, and one bidder has the following valuations:

Combination	Value
100 MHz in X	1.350
60 MHz in X	1.100
100 MHz in Y	1.150
60 MHz in Y	900

The lot size is 10 MHz and each block has one bidding point. At a price per block of 50 in each band, the bidder bids for 100 MHz in X.

If the price in X rises to 65 per 10 MHz, with an unchanged price for Y, the bidder now prefers to go for 60 MHz in X. If he places this bid, he loses bidding eligibility.

If the price in X rises further to more than 75 per 10 MHz, with an unchanged price in Y, the bidder would prefer to bid for 100 MHz in Y, but cannot switch because he does not have the bidding eligibility to do so.

This can result not only in unsold lots in Y, but also to an inefficient assignment of X.

In a simultaneous multi-round auction, this scenario would mean unsold lots in Y as well, for which no bids were received at any time.

The fact that bidders are not bound by provisional winning bids may well facilitate strategic bidding with the intention of driving

[5] This risk influences bidding behaviour, which in more complex scenarios can result in simultaneous multi-round auctions producing an inefficient result.

prices for other bidders up: as long as there is excess demand in one of the lot categories, a bidder can bid for lots that he does not actually want, without necessarily having to honour these bids.

Similar to the simultaneous multi-round auction there is an incentive in the clock auction to reduce demand early in order to keep prices low. As with simultaneous multi-round auctions this does not necessarily have to result in inefficiency, and in cases where the outcome is inefficient this should lead to a more even distribution of the available spectrum to the bidders.

Evaluation

In spite of the risk of inefficient and unsold lots, a simple clock auction is a potentially relevant procedure – primarily due to its simplicity and the transparency for bidders. This is an option both for regional and national award processes, in conjunction with suitable measures to assign any unsold lots.

The actual implementation should allow bidders to place exit bids if they reduce demand. However, these exit bids should only be fulfilled completely or not all, but never in part, in order to prevent the advantages of the clock auction – in terms of avoiding aggregation risks – from being jeopardised (see discussion on clock-plus variants).

This format can cope seamlessly with a large number of lot categories, and in principle it is also possible to determine the need for guard blocks in each region endogenously, by reducing the number of available blocks by one in each case if bidders with different uses bid in the region.

To tackle the issue of inefficient and unsold lots, however, it must be possible to award any unassigned frequency blocks in a suitable follow-up procedure.

For this we need to understand why some lots remain unsold.

Lots can remain unsold for various reasons:

- Firstly, lots can simply be unsold because the rules of activity prevent bidders from bidding for all the lots that they are potentially interested in (see Box 3). Unfortunately, this problem cannot be solved by easing the rules of activity because this would weaken the incentive to disclose demand.
- Secondly, lots can remain unsold because there are complementarities in the increments. For example, if there are synergies up to a maximum LTE-TDD channel width of 20 MHz, then with 10 MHz lots the first, third or fifth blocks are potentially worth less than the second, fourth or sixth blocks. In this case, bidders possibly reduce their demand in twos, and this creates unsold lots that cannot even be avoided with exit bids. Theo-

retically this problem could be countered by selecting lot sizes which have no complementarities between the increments.
- Thirdly, lots can remain unsold because there are additional complementarities (as in the first example in Box 3 for instance). This problem means that some bidders exit completely instead of reducing their demand.
- Fourthly, the expectation of being able to acquire unsold lots more cost-effectively in a follow-up process can result in not all of the lots being awarded.

If a simple clock auction is chosen as the auction method, the following adjustments should be taken into account:

- If it emerges that there are synergistic valuations for additional spectrum up to the maximum channel width (i.e. the value of an additional 20 MHz is more than twice as high as the value of an additional 10 MHz), a lot size of 20 MHz should be chosen. This means that a 10 MHz block in band 42 would need to be retained as a guard block, and if it is not needed, it can be awarded to a bidder at the assignment stage (this award disregards any relevant frequency caps).
- It should be at the discretion of the auctioneer to deviate from the default situation in which unsold lots are retained for a minimum period, and to offer such lots in a sealed bid process during a potential follow-up auction. It should also be at the discretion of the auctioneer whether participation in such a process is reserved for bidders who bought no spectrum at the main auction, or whether the only bidders permitted are those that won frequencies at the main auction. This decision should be dependent on the probable reason for the unsold lots (i.e. whether lots largely remain unsold because some bidders reduced their demand from a relatively large spectrum assignment to zero, or whether lots are predominantly unsold because the relative prices changed after bidders reduced their bidding eligibility). If bidders are permitted that acquired spectrum in the main auction, then the minimum bids in the follow-up auction should not be lower than the bids these bidders placed for the relevant frequencies in the main auction.

In terms of information policy, limited transparency would be advisable, just as for the simultaneous multi-round auction. If the format is used for a national award, the excess demand should be communicated in broad categories, just as for the simultaneous multi-round auction. In the event of a regional award, the larger number of bidders and the greater complexity probably justify higher transparency, and so it would be better to disclose the exact excess demand to bidders.

3.2.3 Clock plus variant

Description

The likelihood of lots remaining unsold can be reduced in a clock auction by additional restrictions being placed on bidders. Such changes were made for example in the US Incentive Auction or the recent frequency auctions in Singapore.

These changes allow the auctioneer to accept bids only in part. The following additional limitations apply in particular:

- A bidder can only reduce the demand in a lot category if there was excess demand in that lot category in the preceding round; otherwise, the bids must be maintained – comparable to provisional winning bids in a simultaneous multi-round auction.
- If a bidder switches from one lot category to another, this switch is only accepted to the extent that this does not lead to excess supply in the first lot category. For example, if a bidder bidding for six lots in a region in band 42 wants to switch to band 43, and this switch leads to excess supply of two lots in band 42, then this switch request will only be fulfilled to the extent of four lots, i.e. the bidder's actual bid will comprise two lots in band 42 (at the clock price of the previous round) and four lots in band 43 (at the current clock price).
- If a bidder reduces his demand, he must submit an exit bid, which can be satisfied to the extent that is required so that no unsold lots remain. For instance, if a bidder bidding for four lots in a category wants to withdraw from the auction completely, he must submit an exit bid for these four lots amounting to at least the previous round price. If the reduction in demand results in excess supply of two lots in that category, and ends the auction, then the bidder must purchase two lots at the price of his exit bid.

Pros and cons

The clock plus variant reduces the risk of unsold lots: unsold lots can then only arise if there was excess supply in a lot category in the first round. Otherwise it is certain that all lots will be sold. Since bids are binding, if their withdrawal would lead to an excess supply it is riskier for bidders to submit bids to drive prices up: there is always the risk that such bids will have to be honoured at the respective price.

These benefits are offset, however, by the fact that bidders are exposed to the same aggregation risk as in a simultaneous multi-round auction. The risk is even more pronounced than in a simultaneous multi-round auction, where bid withdrawals are permitted only to a limited extent, or in a hybrid procedure, in which there can only be one bidder in each lot category whose demand is only partially satisfied.

In comparison to a simultaneous multi-round auction, a clock plus auction is much more complex though. With several lot categories, bidders have to specify a list of priorities if they want to switch, which regulates which switch requests are accepted where applicable. For example, if a bidder wants to give up completely his demand of six lots in one region and instead bid for one additional lot in six other regions, he has to specify the order in which these switch requests should be accepted, if the entire demand cannot be withdrawn from the region. There is always uncertainty regarding how bids actually accepted will appear, which complicates participation for bidders.

Evaluation

Like a simultaneous multi-round auction, the clock plus variant is suitable for a national but not for a regional award, because the aggregation and substitution risks would be unreasonably high for the latter option. Given the greater complexity, the clock plus variant would be inferior to the simultaneous multi-round auction though.

The potential disadvantage of the simultaneous multi-round auction with regard to the number of rounds required to achieve higher prices for a group of essentially identical lots can simply be eliminated by using a hybrid procedure with a standard price per lot category (see chapter 0).

Nevertheless, should a clock plus format be deployed, an information policy similar to that for a hybrid simultaneous multi-round auction should be selected.

3.2.4 Clock auction with ‘clinching’

Description

H3A presented a paper produced by Power Auctions which recommends the use of a clock auction with ‘clinching’.

This format is based on the procedure recommended by Ausubel for the award of several homogeneous products,[6] and has several attractive features under certain conditions.

The format works largely in the same way as a simple clock auction, but with the difference that a bidder is awarded lots at the given round price in a round where the demand of all other bidders falls below what is offered. Box 4 explains this procedure by means of a simple example.

Box 4: Clock auction with 'clinching' - a simple example

Let us assume there are three bidders, A, B and C, who bid for ten lots in total.

The clock price in the first round is 100, and each of the bidders bid for four lots.

In this case, the collective demand from B and C is eight, which means two lots remain unsold if bidder A does not take part. Both of these lots can be awarded to A at a price of 100. The same applies to B and C – either of these bidders can be awarded two lots at a price of 100.

Overall though, there is excess demand, i.e. the clock price rises and there is another round. Let us assume the bidders uphold their bids and the clock price continues to rise until it reaches 200 and bidder C reduces his demand to three lots. The total demand of B and C is seven, so there would be three unsold lots if A does not take part in the auction. It is now possible for A to be awarded a further lot at a price of 200. The same applies for B. The situation for C has not changed.

Let us assume the price continues to rise until it reaches 300 and bidder B reduces his demand to three lots as well. This ends the auction and the lots are assigned as follows:

- A: two lots at a price of 100, one lot at a price of 200, and one lot at a price of 300.
- B: two lots at a price of 100, one lot at a price of 200
- C: two lots at a price of 100, one lot at a price of 300.

The prices at which lots are awarded reflect opportunity costs.

- For the lots awarded to each bidder at a price of 100 there would be no other buyer in the event the bidder did not take part in the auction.
- The price at which the third lot is awarded to A and B reflects the value that C attributes to his fourth lot.
- The price at which the fourth lot is awarded to A and C reflects the value that B attributes to his fourth lot.

Pros and cons

The advantage of the format is that an efficient result is guaranteed under certain conditions: Awarding lots based on opportunity costs ensures that there is an incentive for bidders to place truthful bids.

[6] Ausubel, L (2004) "An Efficient Ascending-Bid Auction for Multiple Objects," *American Economic Review* 94(5)

In particular, there is no incentive to reduce one's own demand early in order to keep prices low. As is clearly illustrated in the example in Box 4, bidders A and B benefit from the reduction in demand by bidder C.[7]

However, this advantage only applies under certain conditions – in particular where marginal valuations for homogeneous products decrease.[8] As shown by the example in Box 5, the result is not necessarily efficient if there are complementarities.

[7] It is still not known, however, just how much the mechanism enables bidders aiming to drive prices up for their rivals to do so without this having any negative consequences on their own prices. This disadvantage of the generalized Vickrey auction, also mentioned by Power Auctions in the CCA assessment, lies in the fact that, with their bids, bidders effectively determine their competitors' prices but not their own.

[8] As emphasised by Ausubel, with private, independent valuations the procedure leads to the same result as the Vickrey auction based on sealed bids, but without bidders having to disclose their entire valuations. With interdependent valuations the procedure can lead to efficient results, whereas the Vickrey auction is not efficient owing to generalisation of the 'winners curse' problem. However, this analysis only applies for a category of homogeneous lots, and decreasing marginal valuations.

Box 5: Clock auction with 'clinching' – inefficiency with complementarities

Let us assume there are three bidders, A, B and C, who bid for three lots. The valuations of the bidders for the lots are as follows:

	1 lot	2 lots	Incremental value
Bidder A	0	10	10
Bidder B	10	19	9
Bidder C	4	8	4

The efficient result is to award two lots to bidder B and one lot to bidder C.

If the bidders bid on the basis of their valuations, the clock rounds ensue as follows:

Round / Price	Demand				Residual demand		
	A	B	C	Total	B+C	A+C	A+B
1	2	2	2	6	4	4	4
2	2	2	2	6	4	4	4
3	2	2	2	6	4	4	4
4	2	2	2	6	4	4	4
5	2	2	0	4	2	2	4
6	2	2	0	4	2	2	4
7	2	2	0	4	2	2	4
8	2	2	0	4	2	2	4
9	2	2	0	4	2	2	4
10	2	1	0	3	1	2	3

In round 5, bidders A and B are each awarded one lot at a price of 5 (the demand of B and C, or A and C, is lower than what is on offer). The auction is not finished though because there is still excess demand.

From round 6, bidder A has to decide whether to stop bidding or not. In this case he wins one single lot, at a price of 5, which is of no value to him. To minimise his loss, the bidder can also continue bidding – potentially up to a price of 10 for the second lot (i.e. 15 in total).

The auction ends either with two lots for A and one lot for B, or – if A does not bid up to the maximum point of indifference – then with two lots for B and one lot for A. Both results are inefficient.

Power Auctions accepts that the proposed format does not solve the aggregation risk problem because the bids cannot be evaluated as a package bid. However, Power Auctions assumes that aggregation risks are negligible because serious bidders should be in a position to acquire the minimum spectrum requirement.[9]

An additional problem arises if the lots available are not homogeneous, and are spread between several lot categories instead, be-

[9] This obviously would mainly apply if only the three mobile network providers participate in the auction, and the spectrum caps are set at 160 MHz, because then every bidder would automatically receive 70 MHz at the minimum price.

cause here the category in which the lots should be awarded is not clear: if the bidders are allowed to switch between lot categories, lots can always be awarded to a bidder using the outlined procedure in the event that the overall demand of the other bidders across all lot categories (expressed in a common ‘currency’, such as bidding points) falls short of the entire supply across all lot categories (in the same currency).

In this context, the proposals by Power Auctions present a problem. For example, Power Auctions suggests:

- auctioning both bands sequentially; or
- using only one lot category, but one product design, in which a 10 MHz block automatically includes 5 MHz in each band; or
- initially using only one lot category, then during an additional stage allowing the winners to distribute the blocks purchased in the auction between the two bands, before the specific frequencies are assigned; or
- carrying out the format with two lot categories, and deciding retrospectively the band in which the blocks assigned under the clinching rule should be located.

Although they are limited to no more than two lot categories (i.e. the bands), these proposals create aggregation and substitution risks, uncertainty for bidders, and additional complexity. A regional structure is not considered in the paper (not even mentioned in fact).

Evaluation

This procedure is ideal for the award of many homogeneous products where valuations are not super-additive. The main advantage is that with this format there are no incentives to reduce demand to keep prices low, and so the auction can be carried out with full transparency across all bids.

Where there are complementarities, however, this procedure does not lead to an efficient result. Where there are several lot categories, it cannot be deployed without changes, which results in very complex rules and nullifies many of the benefits inherent in the simple variant.

The procedure is not suitable for a regional award. Even in the event of a national award, its advantage over a simultaneous multi-round auction should be weighed.

If the format is employed as part of a national award, it should be considered that with realistic frequency caps it is not improbable that a significant part of the frequencies available will be awarded at the minimum bid.[10]

3.2.5 Combinatorial clock auction

Description

The combinatorial clock auction combines a range of open bidding rounds in which, as in a simple clock auction, bidders specify the frequency packages requested by them in each lot category at the respective clock prices, with a sealed bid round, in which bidders can submit additional package bids for combinations of spectrum assignments. The auctioneer then determines the combination of all bids that maximises the proceeds and which can be satisfied with the supply on offer, with no more than one bid selected from each bidder. Successful bidders do not pay the amount of their bid but an opportunity cost price, which is determined by the 'minimum revenue core price' rule. This price is the lowest amount the individual winners and all conceivable groupings of winners collectively could have bid without changing the result of the auction.

Rules of activity limit which bids the individual bidders can submit in the clock rounds, and which bid amounts can be selected for supplementary bids. The specific rules of activity play a crucial role here.

The procedure was first employed in Austria for the award of the 2.6 GHz band, and was also used in the 2013 multiband auction. Recently it was used in Ireland for the award of the 3.6 GHz band at regional level.

Pros and cons

One advantage of the procedure is that bidders are exposed to no aggregation risks at all, because bids are evaluated as package bids and either accepted in their entirety or rejected but never accepted in part. In principle, bidders are able to state their preferences via multiple alternative packages.

[10] For example, if we assume that during a national award only the three mobile network operators take part in the auction, the frequency caps are 160 MHz and every bidder bids for the maximum possible amount in the first round, every bidder would be assigned 70 MHz (390 MHz – 2x160 MHz) at the minimum bid – i.e. more than half of the available spectrum.

At the same time, the procedure has been criticised. The theoretical criticism often levelled is that the advantages of the pure Vickrey prices – in terms of the incentive to make truthful bids – are lost by adjusting the core prices. In practical terms, on the other hand, the criticism relates rather to the uncertainty about prices and the final outcome of the auction:

- the pricing rule makes it particularly difficult for bidders with limited budgets to plan their bidding strategy;
- as this is effectively a sealed bidding round, bidders are exposed to the risk of ending the auction empty-handed under certain circumstances.

The pricing rule is also criticised for allowing bidders to drive up the prices their rivals will have to pay, by submitting bids for large packages where the probability of winning is negligible.

Even though it is unclear how relevant the theoretical concerns are, the practical criticism should be taken seriously.

In fact, the evolution of the rules of activity for the CCA can be construed as an embodiment of the efforts to take account of these concerns. The rules of activity for the Irish 3.6 GHz auction differ from the rules for the Austrian multiband auction, as the following examples illustrate:

- in the clock rounds, the restriction of rules of activity being based solely on bidding eligibility was eased, and bidders were able to make clock bids for larger packages than their bidding eligibility permitted, provided this was consistent with the preferences they had expressed through their previous bidding behaviour;
- in addition to the relative caps, the maximum amounts for supplementary bids were capped based on the final clock prices.

These changes mean that bids which otherwise can only be placed first in the supplementary round are now possible in the clock stage. Consequently, prices in the clock round are better predictions of what the successful bidders will have to pay. At the same time, the number of 'unsold' lots in the final clock round, which generates uncertainty about the ultimate result, is minimised. The introduction of the final price cap makes it easier for bidders to calculate a bid with which they can secure their final clock bid.

In spite of these changes, the criticism levelled against the CCA is valid, at least in principle: the format is not a 'pay-as-bid' procedure and includes elements of a sealed bid.

Evaluation

As demonstrated by the Irish 3.6 GHz auction, the CCA is certainly suitable for a spectrum award of this size, at regional level as well.

There is no cause for concern regarding the efficiency of the outcome in this procedure.

For practical reasons it will in all likelihood be necessary to limit the maximum number of packages that a bidder can bid for. The actual limit depends on the number of participants, but will not be less than 500 bids per bidder.

If this format is employed, consideration should be given to adapting the rules of activity in such a manner that makes the outcome of the clock rounds more relevant for the actual auction outcome. The rules of activity of the Irish auction (easing of rules of activity in the clock stage and application of a 'final price cap') would be a good start in this case. Given the experience with the multiband auction, however, greater transparency than seen in the Irish auction would be advisable, which means bidders should be informed at the end of each round about the aggregate demand in each lot category.

3.2.6 Combinatorial multi-round auction (CMRA)

Description

A combinatorial multi-round auction is a format that combines the advantages of the simultaneous multi-round auction in terms of transparency and bidder control over the auction outcome with the benefits of more flexible package bids. As in simultaneous multi-round auctions, a CMRA:

- has a simple pay-as-bid rule for the prices – successful bidders pay the amount of their winning bid; and
- a condition for determining the end of the auction procedure (a 'final condition'), which allows bidders to place new bids as long as they are not in a winning position with any of their previous bids (in contrast to simultaneous multi-round auctions, bids are evaluated in their entirety).

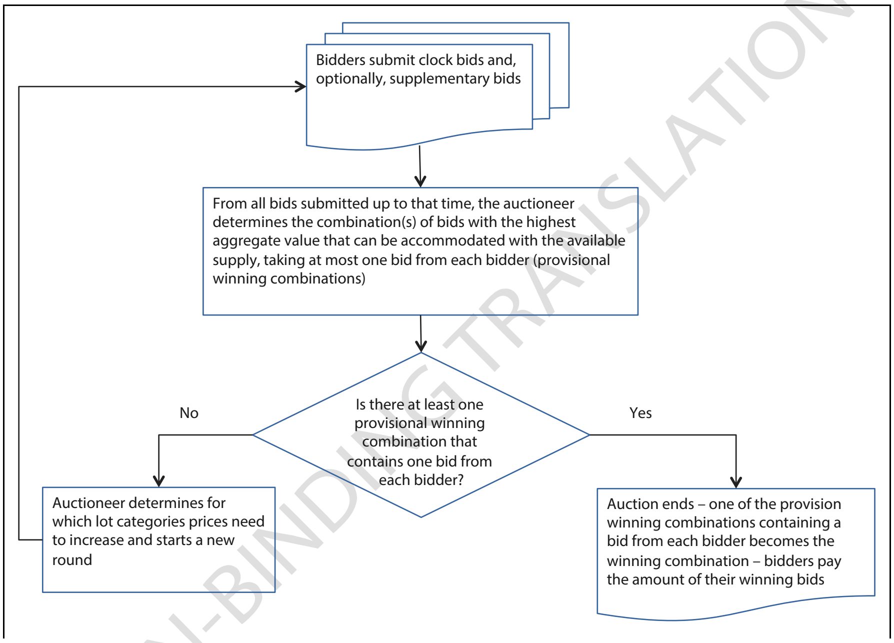
This means that a bidder may only leave the auction empty-handed if he has explicitly accepted such an outcome.

The CMRA also supports flexible package bids, which are either accepted in full or not at all, thereby eliminating potential aggregation risks and enabling simple switches between various alternative spectrum portfolios.

In terms of procedure, a CMRA resembles the clock stage of a CCA. However, in addition to the clock bid in a round, bidders can also submit package bids ('supplementary bids'), which together with the clock bids are included to provisionally determine the winners at the end of each round. This means that at the end of each round the auctioneer determines the combination of all bids that maximises the proceeds and which can be satisfied with the supply on offer, with no more than one bid selected from the clock and supplementary bids placed by each bidder. This combination constitutes a provisional winning combination.

When there is at least one provisional winning combination that contains exactly one bid from each bidder, the auction ends. If there is only one provisional winning combination that fulfils this condition, this becomes the winning combination. If there is more than one provisional winning combination that contains exactly one bid from each bidder, one of them is determined the winning combination based on appropriate tie-breaking rules. Every bidder is assigned the lots from his winning bid, and pays the respective bid amount. Accordingly, a bidder may fail to be awarded lots only if that bidder placed a bid during the auction that contained no lot whatsoever ('zero bid').[11] Figure 3 shows the procedure in a CMRA.

Figure 3: CMRA procedure



The supplementary bids in the CMRA play a similar role to the supplementary bids in a CCA: they reveal which alternative packages a bidder would accept, and at what price. In contrast to a CCA though, these additional bids can be introduced gradually, and there is no risk for bidders to possibly leave empty-handed because they did not place a certain supplementary bid. As long as the final condition is not met, bidders always have the opportunity to bid in the next round.

[11] A bidder is also considered to have placed a zero bid if he did not place a valid bid before the end of the round (whereby the end may be postponed by exercising extension rights).

As in a CCA, the clock bids determine the activity of bidders and their bidding eligibility. As in a CCA, the supplementary bids for packages which are higher than the bidder's bidding eligibility are subject to relative caps. That said, bidders are also allowed to make clock bids for packages that are larger than their current bidding eligibility permits ('relaxed clock bids'), provided that the bid amount is compatible with the relative caps that would apply for the package if the bid were placed as a supplementary bid. Box 6 contains an overview of the rules of activity for the CMRA.

Box 6: CMRA rules of activity

Bids and bid amounts

The amount of a clock bid is calculated from the amounts specified by the bidder and the given round prices.

The amount of a supplementary bid can be chosen at will subject to the following restrictions:

(a) The bid amount may not exceed the price of the package at the round price.
(b) The bid amount may not fall short of the package price at the minimum bid level.
(c) The bid amount must be compatible with any relative caps where applicable.

Activity and bidding eligibility

The bidding eligibility of a bidder, expressed in bidding points in the first round, is determined during registration and is based for example on the bank guarantee to be provided by the bidder.

In each of the following rounds, the bidding eligibility is the minimum bidding eligibility from the previous round and the activity in the previous round associated with the (unrelaxed) clock bid of the bidder.

Use of relative caps

Bidders whose activity exceeds their current bidding eligibility can place bids for packages. Such bids can be supplementary bids or clock bids. The latter are termed relaxed clock bids and are not relevant for determining bidding eligibility.

The amounts of these bids must be compatible with relative caps calculated in accordance with the same principles used for the caps in the 2.6 GHz auction or the multiband auction in 2013 (see, for example, rules of procedure for the 2.6 GHz auction[12], with the relevant examples from p. 34).

An example for the application of the final condition is contained in Box 7.

[12] https://www.rtr.at/en/tk/FRQ_2600MHz_2010_VA/26739_F4_08_Webversion_nonbinding_Rules_of_Procedure_2_6GHz.pdf

Box 7: Application of final condition

Let us assume that three bidders A, B and C bid for ten lots in each of two categories X and Y. Let us assume the bidders have only placed clock bids for one package each in the auction so far. The round price is 10 in each category, and the bids placed are as follows:

Bidder	Clock bid	Supplementary bids
A	**(5X, 5Y) @100**	
B	**(5X, 5Y) @100**	
C	(5X, 0Y) @ 50	

The provisional winning combination comprises clock bids from A and B (in bold in the table below). Bidder C would win nothing. This means another round is necessary. Since C's clock bid only contains lots in category X, the price for X must go up to allow C an opportunity to win with his bid. Let us assume the new price for X is 11, and the bidders place the following bids:

Bidder	Clock bid	Supplementary bids
A	**(5X, 5Y) @105**	
B	(0X, 0Y) @ 0	**(5X, 5Y) @100**
C	(5X, 0Y) @ 55	

The clock bid from B in the previous round automatically becomes a supplementary bid, and the provisional winning combination is now the award of A's clock bid and B's supplementary bid. C still ends up empty-handed. This means that although the clock bids could be satisfied in the round with what is on offer, the auction still proceeds to the next round. The price of X rises again to 12. The bids are now as follows:

Bidder	Clock bid	Supplementary bids
A	(0X, 5Y) @ 50	**(5X, 5Y) @105**
B	(0X, 0Y) @ 0	(5X, 5Y) @100 **(0X, 5Y) @ 50**
C	**(5X, 0Y) @ 60**	

It should be noted that B can still place bids that are compatible with the rules of activity. While the package (0X, 5Y) is larger than the bidder's current bidding eligibility – zero – the bid amount is not higher than the difference in price between the package the bidder actually bid for (0X, 0Y) in the round when he was last able to bid for it (0X, 5Y), and the package that was bid for, at the given prices for the round.

The provisional winning combination now contains A's supplementary bid, B's second supplementary bid, and C's clock bid. Since the provisional winning combination comprises one bid from each bidder, the auction ends and the bidders are assigned their respective winning bids at the respective bid amounts.

The example in Box 7 shows that another round can be necessary even though, based on the clock bids, there is no excess demand in any lot category in a round. This is why the question about which prices have to increase cannot simply be answered by referring to excess demand from clock bids. Rather, the lot categories must be determined for which the bidders, who are not represented with a bid in all of the provisional winning combinations in a round, must be able to bid to ensure they have one of their bids in each of the provisional winning combinations.

The process for determining the lot categories whose prices have to increase in the event that another round is required is complex for the auctioneer; a more detailed description is contained in Box 8.

Box 8: Process for determining the lot categories whose prices have to increase

The lot categories whose prices have to increase are determined as follows based on the provisional winning combinations:

1) Identify all the bidders who are not represented in each provisional winning combination with one of their bids ('excluded bidders').
2) For each of these bidders:
    a. Identify the last clock bid C and the set L of lot categories in C with a positive demand: L = $\{c_1, c_2, c_3 \ldots c_N\}$
    b. For each lot category c in L:
        i. Create a hypothetical clock bid H, in which the demand in all other lot categories is assigned the value zero (adjusting the bid amount accordingly).
        ii. Replace C with H and re-evaluate all bids; if the bidder is still excluded, the price for this lot category has to rise.
    c. If this procedure does not identify the need for a price increase in at least one lot category, repeat the process for all subsets of L with two elements.
    d. If this procedure identifies no need for a price increase, repeat the process for all subsets of L with three elements ... etc. up to L.*

    Proceed to the next bidder.

This process ends as soon as the need for a price increase has been identified for each lot category.

*For practical reasons it may be necessary to carry the process out only for certain subsets of L.

Pros and cons

The advantage of the CMRA is that it permits flexible package bids and thereby eliminates all aggregation risks. Bidders can voice their preferences for different spectrum portfolios and are restricted in no way by the rules of activity as long as these preferences are implemented consistently in the bids.

At the same time, the format gives bidders certainty about what they will have to pay for a package they are bidding for if they win it. Bidders have no direct influence on which packages they can potentially win from among those they have bid for – what they can influence though is the extent to which and at what time they can bid for alternatives that they are satisfied with at the respective bid amount. A bidder that is only interested in a specific package may, for instance, bid solely for this, as long as this is in line with his budget, and then switch to the next best alternative, without being exposed to the risk of possibly finishing the auction empty-handed.[13]

Like all combinatorial auction formats, one disadvantage of the CMRA is its higher complexity. Even though a large part of the complexity rests with the auctioneer, bidders have to think about when they would like to bid for supplementary packages, and possibly manage a portfolio of package bids (even if the bidders determine the sizes of these portfolios themselves). However, this complexity is also seen in other formats, in which a simpler method of bid submission exposes the bidders to various risks which have to be evaluated and to which the bidders must respond appropriately. A further disadvantage is that the format has actually been used in only one procedure thus far, and so bidders have little experience with it.

Evaluation

The CMRA is suitable for both a regional and a national award process. The format supports flexible package bids and should result in an efficient assignment of frequencies. At the same time, bidders enjoy full certainty about the prices they have to pay. As a 'pay-as-bid' format there is no opportunity for bidders to influence the prices of rivals by placing bids that they do not win (and do not want to win). Bidders have control over the potential outcomes and are exposed to no risk of ending the auction empty-handed if they have not explicitly accepted such an outcome.

The procedure works with lot sizes of 10 and 20 MHz, and if 10 MHz lots are selected, it is relatively easy to reserve a guard block for the event that differing user types win.

For practical reasons it can be necessary to limit the maximum number of bids that a bidder may place. This restriction ultimately depends on the number of participants, but will not be less than 500 bids per bidder. In any event, such a limit should not represent a material restriction, considering that bidders have an interest in a relatively restricted number of packages and there is no need to offer a large number of alternatives to minimise the risk of potentially ending up empty-handed. Nevertheless, in this case it would make sense to choose a lot size of 20 MHz to keep the number of potential packages more manageable.

[13] This does not rule out the bidder winning his preferred package – but this will always be at a price at which he favours this package over the next best alternative.

The process for determining the lot categories whose prices have to rise should, in principle, send relatively precise pricing signals to bidders, showing them where their demand conflicts with that of other bidders. The aggregate demand from clock bids itself is not a reliable indicator for this, but bidders can tell from this information whether the provisional winning combinations contain supplementary bids or, based on the clock bids, whether there would be unsold lots.

To make it easier for bidders to decide whether to submit supplementary bids, and which ones to submit, disclosing the following additional information should be considered:

- for every lot category, the number of active bidders in this category, whereby activity in this context is defined as the bidder having submitted a clock bid which contains lots in the category, or having submitted or updated in the given round supplementary bids which contain lots in this category;
- for every bidder, whether the bidder is 'excluded' from the given round, i.e. not represented in every provisional winning combination;
- potentially for every bidder, which of their bids are included in a provisional winning combination.

A discretionary decision is required in relation to the optimal level of transparency, and it would appear useful to provide more information in the case of a regional award.

3.3 Design of the assignment stage

The object of the assignment stage is to assign contiguous frequencies to the spectrum winners in the principal stage. As far as possible, bidders that win frequencies in more than one region are assigned the same spectrum, which means differences in frequency assignment to bidders across regions should be minimised.

In principle, the assignment of specific frequencies can be left to negotiations between successful bidders (where the regulatory authority can prescribe band plans it deems acceptable). Yet since such negotiations are not necessarily simple, or lead to an outcome quickly enough, there needs to be an alternative procedure to resorted to in the event of failure. Furthermore, the assignment stage can include the assignment of additional usable frequencies (if, for example, a lot size of 20 MHz is used and the guard block retained in band 42 in this case is not required, or an auction procedure is chosen where the need for a guard block cannot be considered on a situation-specific basis, as in the case of a simultaneous multi-round auction for example).

Given the relatively low value most probably put on specific frequencies being assigned, and given the limited number of possible assignments, the most appropriate option for this procedure would appear to be a sealed bidding round with prices determined based on opportunity costs. This procedure is the same as that applied in the multiband auction and the 2.6 GHz auction.

The main challenge is identifying the assignment options. In this context, the following principles should be applied:

- If different user types win in band 42, then type 1 standard users are placed at the upper end of the band, and type 2 standard users at the lower end of the band. The guard block of 10 MHz is assigned to standard user 1 in the lowest range.
- If only type 1 standard users win in band 42, and a 10 MHz guard block has been retained, this is assigned to the standard user 1 in the lowest range.
- If only type 2 standard users win in band 42, then the 10 MHz guard block is assigned to the user in the lowest range in band 43.
- Within every user group, bidders are arranged in the same order across all regions.
- The order in which the bidders are arranged is determined in such a way that the variation in the spectrum assignment across the regions is minimised, and any unsold blocks can be used as 'fillers' to ensure better alignment.

The procedure applied in Ireland[14] for example can be used to implement these principles. Alternatively, another conceivable process is where the bidders or groups of bidders are assigned identical spectrum at national level are placed at the ends of the respective bands, and the other winners are arranged around the middle of the band (or at the lower end of the band in the case of band 43); within each group, the respective winners are arranged in different orders. This is illustrated by the example in Box 9.

[14] For a more accurate description see Annex 9 of the Information Memorandum (ComReg 16/71), https://www.comreg.ie/media/dlm_uploads/2016/08/ComReg-1671.pdf

Box 9: Determining assignment options – two examples

For simplicity's sake, we look at four regions. We define the regional bandwidth variation (RBV) as the difference between the maximum and minimum number of blocks that a bidder or a group of bidders has won across all regions.

Example 1: Let us assume that the following bidders have won the following number of 10 MHz blocks in band 42 in these regions:

	Asymmetric			Symmetric				
	A	B	C	D	E	F	Guard block	Unsold
R1	7	6	4	0	0	0	0	2
R2	7	6	0	5	0	0	1	0
R3	7	7	0	0	2	2	1	0
R4	7	5	0	0	4	0	1	2

For bidder A, for example, the RBV is zero because he has won the same number of blocks in every region. For bidder B, the RBV is 7 – 5 = 2. For the total group of bidders D, E and F, the RBV is 5 – 4 = 1.

Step 1: Identify bidders or groups of bidders with an RBV of zero and place them at the corresponding band end:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1													A	A	A	A	A	A	A
R2													A	A	A	A	A	A	A
R3													A	A	A	A	A	A	A
R4													A	A	A	A	A	A	A

Step 2: Place the other bidders in the various orders, with the unsold lots remaining between the user groups.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	U	U	C	C	C	C	B	B	B	B	B	B	A	A	A	A	A	A	A
R2	D	D	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	F	F	E	E	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	E	E	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	U	U	B	B	B	B	B	B	C	C	C	C	A	A	A	A	A	A	A
R2	D	D	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	F	F	E	E	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	E	E	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	U	U	C	C	C	C	B	B	B	B	B	B	A	A	A	A	A	A	A
R2	D	D	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	E	E	F	F	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	E	E	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	U	U	B	B	B	B	B	B	C	C	C	C	A	A	A	A	A	A	A
R2	D	D	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	E	E	F	F	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	E	E	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

In this case, the unsold lots cannot be used to improve the alignment, and thus remain in their respective positions.

Example 2: Let us assume the frequency packages won by the bidders are as follows:

	Asymmetric			Symmetric				
	A	B	C	D	E	F	Guard block	Unsold
R1	7	6	2	0	0	2	1	1
R2	7	6	0	3	0	2	1	0
R3	7	7	0	2	2	0	1	0
R4	7	5	0	2	2	0	1	2

In this case, we can combine bidders E and F into one group, whose RBV is also zero, which results in the following after the first step:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	F	F											A	A	A	A	A	A	A
R2	F	F											A	A	A	A	A	A	A
R3	E	E											A	A	A	A	A	A	A
R4	E	E											A	A	A	A	A	A	A

The arrangement of the remaining bidders then results in the following two band plans:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	F	F	U	G	C	C	B	B	B	B	B	B	A	A	A	A	A	A	A
R2	F	F	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	E	E	D	D	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	D	D	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
R1	F	F	U	G	B	B	B	B	B	B	C	C	A	A	A	A	A	A	A
R2	F	F	D	D	D	G	B	B	B	B	B	B	A	A	A	A	A	A	A
R3	E	E	D	D	G	B	B	B	B	B	B	B	A	A	A	A	A	A	A
R4	E	E	D	D	U	U	G	B	B	B	B	B	A	A	A	A	A	A	A

As in Ireland, it should be possible for bidders to bid as a consortium in the assignment stage (as long as the combination of bidders is compatible with the spectrum caps and no bidder is a member of more than one bidding consortium). To determine the assignment options, bidders within a bidding consortium are treated as a single winner, and they are responsible for assigning to the individual members the frequencies won by the consortium (such assignments must be contiguous within a region).

It should also be possible for bidders to negotiate on adjustments to the frequency assignments after the assignment stage, in order to take advantage of any improvement opportunities.

4 Summary

This document discusses the product and auction design options relating to the awarding of frequencies in band 42 and band 43 (3.4-3.8 GHz).

The following proposals for product design are on the table:

- Both bands are considered separately.
- In each band, frequencies are auctioned initially in the form of abstract blocks, with a lot size of either 10 MHz or 20 MHz.
- The award can take place at national or regional level.
- Two standard uses are defined, differentiated by their download/upload ratio. The Consultation on Future Frequency Awards suggests an asymmetric ratio (3:1) for standard use 1, and a symmetric ratio for standard use 2.
- Standard use 1 is specified for band 43. Both standard uses are possible for band 42, with users of the same type placed together in the band (type 1 standard users at the upper end of the band, type 2 standard users at the lower end of the band). The standard user 1 in the lowest range is assigned a block that is effectively used as a guard block between the two user types; this is required because synchronous operation is not possible between the two user types.

The following proposals for auction design are on the table:

- A two-stage procedure should be carried out with a principal stage and an assignment stage.
- For the principal stage, the procedures listed in Figure 4 are options, under the respective conditions.
- For the assignment stage, a sealed-bid procedure should be conducted with an opportunity cost rule similar to the procedure applied in the 2.6 GHz auction and the multiband auction.
- The assignment options relevant for the bidders should be specified in such a way that bidders winning spectrum in more than one region are assigned identical frequencies where possible.
- It should be possible for bidders to bid as bidding consortia in the assignment stage. Bidders should also be able to modify the result of the assignment stage through negotiations.

Figure 4: Methods for the principal stage

Methods	Conditions and comments
Simultaneous multi-round auction	Not suitable for regional awards, but may be used for national awards Should be conducted in a hybrid form in which a price is determined for all lots in a category, and bidders then specify the number of lots they would like
Simple clock auction	Suitable for both a regional and a national award process 'Exit bids' permissible 20 MHz lots where appropriate Possibility of a follow-up process for unsold lots, at discretion of auctioneer Drawback: potential for inefficient, unsold lots
Clock plus variant	Conditions for use the same as for simultaneous multi-round auctions; the clock plus variant is inferior owing to the greater complexity.
Clock auction with 'clinching'	Not suitable for regional awards. Also problematic for national awards owing to problems with more than one product category, and therefore inferior to simultaneous multi-round auction
CCA	Essentially suitable for both regional and national awards, but not recommended owing to criticism following the multiband auction If employed, then using rules of activity that bring the outcome closer to the final outcome of the clock stage.
CMRA	Suitable for both a regional and a national award process More complex than a simple clock auction, but lower risk of inefficient, unsold lots