

# Updated proposals for the award of the spectrum bands 2500-2690MHz and 2010-2025MHz – Part 2

Riverside House, London  
10 September 2007

## Programme for the day

- **Morning Session on Technical Issues** – 10 am to 12.30 pm
  - Welcome and introduction
  - Interference analysis: in-band at 2.6GHz
  - 15 min break*
  - New information and analysis on adjacent users
  - Packaging and use of generic lots
  - Q&As
- **Lunch** - 12:30 pm
- **Afternoon Session on Auction Design** – 2 pm to 4.30 pm
  - Overview of auction design and changes from December Consultation
  - Alternate design features considered
  - Illustration of auction design for 2.6GHz band
  - 15 min break*
  - Final Q&As

## Agenda

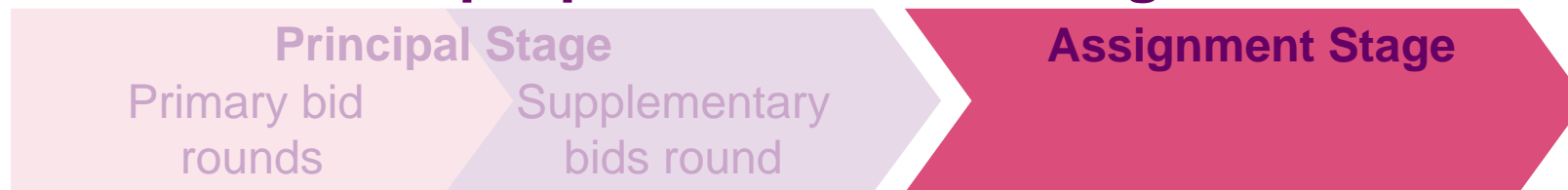
- Section 1 – Overview of auction design and changes from December Consultation
- Section 2 – Alternate design features considered
- Section 3 – Illustration of auction for 2.6GHz band

## Overview of the proposed auction design

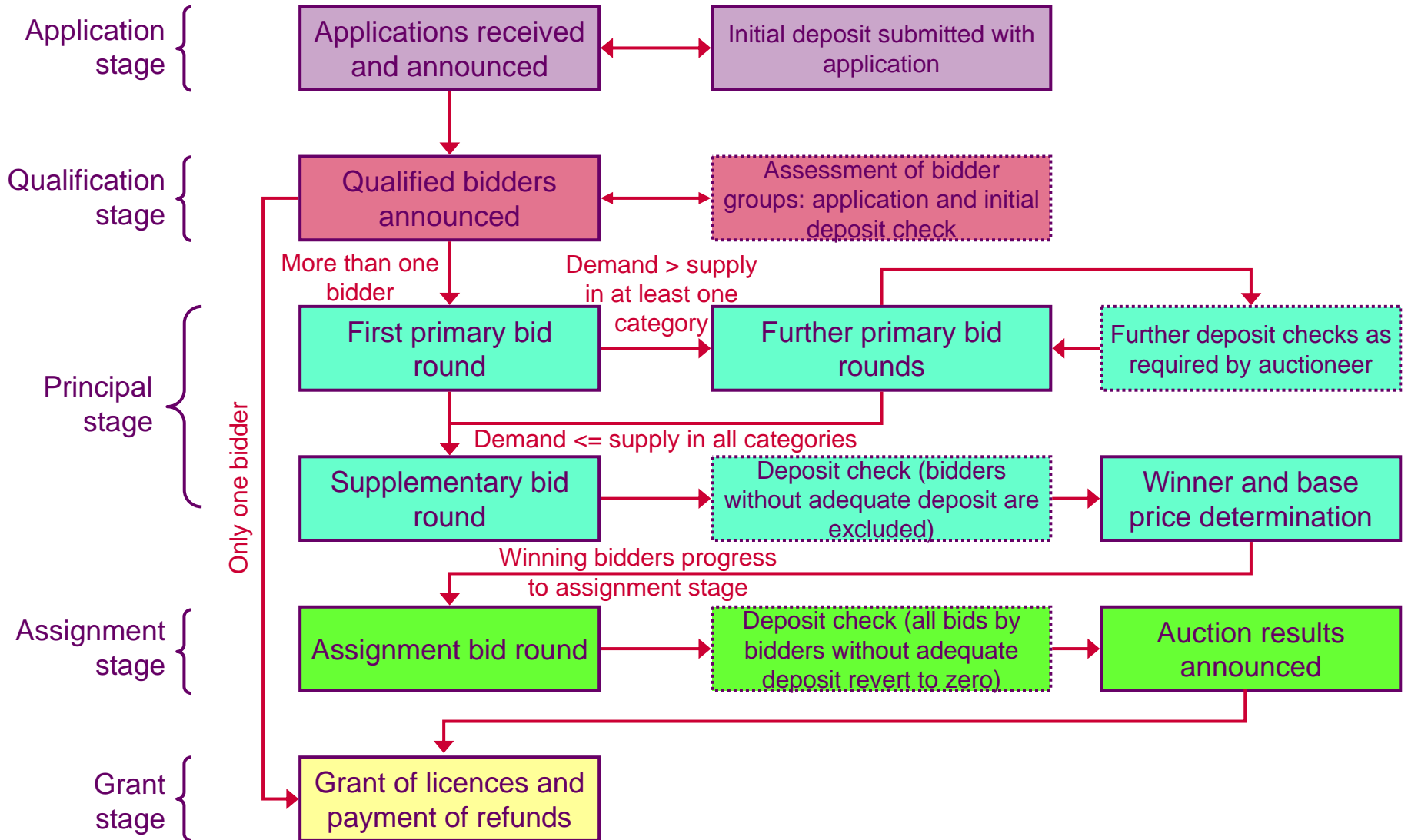


- Three categories of lot: 2010MHz lot, 2.6GHz paired lots, 2.6GHz unpaired lots
- Stage 1 – the Principal Stage consists of two parts
  - Primary bid rounds – an open, multi-round process
    - Bidders bid for a package of lots specifying the number of lots they want within each of the three categories; prices per lot increase from round to round
    - Main activity rules
      - » bidders cannot increase their demand from one round to the next
      - » switching between the three categories is possible
  - Supplementary bids round – a single-round, sealed bid process
    - Bidders can place additional bids consistent with their primary round bids and bidders for unpaired spectrum can additionally bid for split assignments
- The following are determined at the end of Principal Stage
  - winner of the 2010MHz lot
  - split between paired and unpaired spectrum in the 2.6GHz band
  - identity of winning bidders and number of paired / unpaired lots they've won (but not frequencies)... and whether any of the winning unpaired bids are split bids
  - the base prices they must pay for spectrum they have won, using a 'second-price' rule

## Overview of the proposed auction design



- Stage 2 – assignment stage
  - Two parallel single-round sealed bid processes
    - one for 2.6GHz paired lots
    - one for 2.6GHz unpaired lots
  - The options setting out the alternative ways for assigning the spectrum to the winning bidders (in contiguous blocks) are specified
  - Bidders submit assignment round bids - the amount they would be willing to pay *in addition to the base prices determined in the principal stage* for each assignment option (n.b. a bidder could bid zero for all options if indifferent as to which frequencies they are assigned)
  - The winning set of assignments is the highest value combination of these bids
  - The additional price for each bidder is determined using a second-price rule
  - The final price paid is the sum of the base price from Principal Stage and the additional price for each winning option in the Assignment Stage



## Overview of changes since December proposals

- Detailed rules proposed for stages where previously not provided: application, qualification and grant
- Principal Stage
  - Terminology changes
    - “Primary bid rounds” instead of “clock stage”
    - “Supplementary bids round” instead of “best and final offers (BAFO) round”
  - Eligibility applies across all categories, i.e. switching between 2.6 paired, 2.6 unpaired & 2010 will be possible
  - Safeguard cap – the option of 90MHz per bidder is now proposed as the cap
  - Deposits will be required
  - Information policy

## Overview of changes since December proposals

- Primary bid rounds
  - Bids for unpaired spectrum in primary rounds are for non-split assignments only (option to bid on split assignments in supplementary bids round)
  - Price ratio between 2.6 paired & 2.6 unpaired is 2:1 unless demand for 2.6 unpaired falls below 9 lots (the price for unpaired lots is then frozen unless and until demand for 2.6 unpaired subsequently increases to >9 and the price ratio is reintroduced)
  - Extension rights replace waivers. An extension right is automatically used if a bidder fails to submit a bid in time
- Supplementary bids round
  - Supplementary bids will now *only* be submitted in the supplementary bids round, after completion of the primary bids round
  - Supplementary bids round is *always* run
  - Bidders for 2.6 unpaired lots may submit bids for split assignments in this round

## Overview of changes since December proposals

- Winner determination and Base Price derivation
  - Tie-break rules added for winner determination
  - More detail included on determination of base prices for the winning bids
    - Base prices have to satisfy the condition that no alternative bidder or group of bidders would be prepared to pay more than the winner or group of winners
      - » The intuition is that base prices have to be **high enough** so that, given the bids submitted, no losing bidder has made a better offer for one of the winning packages, **but no higher**
      - » The base prices paid by winning bidders therefore depend on the value of bids submitted by the losing bidders (i.e. second price auction)
    - There may be several sets of base prices which satisfy this condition
      - » We take the set of base prices for which the sum total that the winners pay is the **minimum** possible, and closest to the opportunity costs

## Overview of changes since December proposals

- Assignment stage
  - Additional information given on treatment of unsold lots in setting the assignment options
  - Split assignment(s) for unpaired lots in 2.6GHz are only included in the winning combination if bids were made for them
    - A bidder will only receive a split assignment if its winning bid at the end of the principal stage is (or includes) a split assignment
  - Rules for assignment of guard blocks (lot 24 and possibly lot 38) have been included
  - Pricing rule for determining additional prices (top-up bids) has been changed to a 'second price' rule

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## Range of further design options considered

- Responses to the December Consultation raised number of issues that could be addressed through packaging and auction design
  - Effect of blocking (from TDD terminal transmissions in top of band) on value of FDD lots: option to introduce contingent bidding
  - Pairing specific lots at 2.6GHz from the range 2585-2620MHz with other bands at 1.9GHz and 2010MHz: adding options to bid on specific lots
  - Potential variations in the value of lots at different frequencies within the 2500-2690MHz band: option to introduce more categories of lots
- Also considered implications of moving away from generic lot approach (e.g. to 'standard' SMRA)

## Use of contingent bidding to address the blocking effect

- Option: bidders for 2.6 paired and unpaired participate in two, mutually exclusive sub-auctions
  - In one, there is no restriction on the use of unpaired lots within top of band (2620-2690MHz)
  - In the other, unpaired lots within 2620-2690MHz are downlink onlySub-auction with the highest value combination of bids determines outcome
- This approach carries a risk of undesirable and inefficient outcomes
  - Bidders for paired spectrum might adopt an overly conservative approach in the sub-auction where there is no restriction on unpaired spectrum within 2620-2690MHz
  - The number of bids that have to be submitted increases, both in the primary and supplementary rounds and the bidding process becomes more complex; there's more risk that bidders do not submit the full range of bids covering all their preferences, leading potentially to an inefficient outcome
- Potential mitigation such as reserving spectrum for new entrants or imposing a lower limit on the % difference between bids in the two sub-auctions risks are unattractive
- The scale of the blocking effect for FDD bidders looks modest

## Option to use auction design to facilitate external pairing

- Some MNOs requested that the auction facilitate the external pairing of 2570-2620MHz
  - 2600-2620MHz with blocks awarded in 3G auction at 1899.9-1919.9MHz and/or
  - 2585-2600MHz with 2010-2025MHz
- Taking as an example the first pairing, a potential solution could be to introduce
  - 4 new categories of lots are created, one for each 5MHz lot in the range 2600-2620MHz
  - Adjustments to switching rules and winner determination rules
- Assessment indicates this option is not attractive
  - Significant additional complexity around switching rules, determining additional guard blocks, calculating the winning combination of bids
  - Potential value of adding this option is, at best, uncertain
    - The need, in most cases, to buy additional “guard blocks” reduces the attraction of external pairing by comparison with acquiring a paired lot within the 2.6GHz band
    - Feedback suggests that it is unlikely handset manufacturers will develop handsets for these specifications

## Adding more categories of lot

- It has been put to Ofcom that it would be worth establishing additional categories of lots so that their differential value can be expressed during the Principal Stage (rather than the Assignment Stage). E.g. new categories of lot have been suggested to reflect
  - Lots adjacent to an FDD / TDD boundary
  - The impact of radar towards the top of the 2.6GHz band, affecting the value of both unpaired and paired use
  - Unpaired spectrum in the centre of the band possibly being more desirable than unpaired spectrum in the top of the band
- On balance, Ofcom is not minded to introduce more categories of lot because
  - There is a trade-off between adding categories and complexity for bidders and for execution of the auction
  - Adding categories creates more opportunities for strategic manipulation (e.g. hiding intentions by bidding on lots that one doesn't want)
  - Technical analysis does not support a view that the differences in value will be large
  - Bidders can already express differences in value between specific assignments through the Assignment Stage

## Changing auction design to specific lot approach

- A 'standard' SMRA approach would allow bidders to bid for individual 5MHz blocks (not specifying lots outside centre gap as paired or unpaired). Use package bidding so that bidders can acquire contiguous assignments and can bid for lots with right duplex spacing for paired use.
- 'Standard' SMRA approach has advantage that many stakeholders are familiar with it
- But drawbacks in this case are substantial
  - Very much more complex for bidders and auction execution – very large numbers of package bids to submit each round, and high risk that not all will be submitted
  - Harder for the market to drive an efficient allocation between paired and unpaired use
  - Inability to take account of neighbours' use and potential for interference may lead to 'conservative' bidding and inefficient outcomes
  - Risks of strategic behaviour - the SMRA format is vulnerable to gaming behaviour and creates complex incentives for bidders that can lead to inefficient outcomes
- A combinatorial clock format with individual clocks for each 5MHz lot in the 2.6GHz band would suffer from similar drawbacks

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## Description of bidders

### Kenny only wants paired spectrum

- Kenny's willingness to pay for the following packages is:
  - 6 paired lots (2x30MHz) = £1.3 mn
  - 7 paired lots (2x35MHz) = £1.4 mn
  - 8 paired lots (2x40MHz) = £1.5 mn
- An initial deposit of £100k is submitted at the application stage
- Kenny needs an initial eligibility of 16 points if he is to be able to bid for all his packages of interest
- Kenny therefore increases his deposit to £800k before the principal stage begins

### Louise only wants unpaired spectrum

- Louise's willingness to pay for the following packages is:
  - 7 unpaired lots – 35MHz = £725k
  - 9 unpaired lots – 45MHz = £850k
  - Note that the lowest 5MHz will be a restricted use block
- An initial deposit of £100k is submitted at the application stage
- Louise needs an initial eligibility of 9 points
- Louise therefore increases her deposit to £450k before the principal stage begins

*We have used a collective "other bidders" entity in order to simplify the following examples*

## Primary bid round 1

	Paired 2.6GHz	Unpaired 2.6GHz
Price per lot	£100k	£50k

Bids	Number of lots		Eligibility	Total price
Kenny	8		16	£800k
Louise		9	9	£450k
Other bidders	5	6	16	£800k

Total demand (lots)	13	15
Total demand (MHz)	26 x 5MHz	15 x 5MHz
Available supply (MHz)	37 x 5MHz	
Excess demand (MHz)	4 x 5MHz	
New price per lot	£200k	£100k

## Primary bid round 2

	<b>Paired 2.6GHz</b>	<b>Unpaired 2.6GHz</b>
<b>Price per lot</b>	<b>£200k</b>	<b>£100k</b>

<b>Bids</b>	<b>Number of lots</b>		<b>Eligibility</b>	<b>Total price</b>
<b>Kenny</b>	7		14	<b>£1400k</b>
<b>Louise</b>		7	7	<b>£700k</b>
<b>Other bidders</b>	5	6	16	<b>£1600k</b>

<b>Total demand (lots)</b>	<b>12</b>	<b>13</b>
<b>Total demand (MHz)</b>	<b>24 x 5MHz</b>	<b>13 x 5MHz</b>
<b>Available supply (MHz)</b>	<b>37 x 5MHz</b>	
<b>Excess demand (MHz)</b>	<b>No excess demand</b>	
<b>New price per lot</b>	<b>End of primary bid rounds</b>	

## Supplementary bids rounds

### Kenny makes two supplementary bids

- an uncapped one for 6 paired lots
  - we assume Kenny bids his maximum value of £1300k
- a capped one for 8 paired lots
  - in primary bid round 2 Kenny dropped his bid from 8 to 7 paired lots
  - The lot price in round 2 limits the maximum bid he can make i.e.  $8 \times £200k = £1600k$
  - hence **Kenny can bid his maximum value of £1500k** for 8 paired lots
- Kenny could also have increased his maximum bid for 7 paired lots, but has already bid the maximum that he is willing to pay for this package and so chooses not to
- *Note: the supplementary bid round is a single round sealed bid process*

### Louise makes two standard supplementary bids

- an uncapped one for 7 unpaired lots
  - we assume Louise bids her maximum value of £725k
- a capped one for 9 unpaired lots
  - in primary bid round 2 Louise dropped her bid from 9 to 7 unpaired lots
  - The lot price in round 2 limits the maximum bid she can make i.e.  $9 \times £100k = £900k$
  - hence **Louise can bid her maximum value of £850k** for 9 unpaired lots
- For the moment we will assume that Louise is not interested in a split award and so does not make any split supplementary bids

## Determining the winning bids – summary of bids

<b>Kenny's bid summary</b>		
<b>Primary round bids</b>	<b>Number of lots</b>	<b>Total Price</b>
Round 1	8 (16x5MHz)	£800k
Round 2	7 (14x5MHz)	£1400k
<b>Standard supplementary bids</b>		
Supplementary bid 1	8 (16x5MHz)	£1500k
Supplementary bid 2	6 (12x5MHz)	£1300k
<b>Louise's bid summary</b>		
<b>Primary round bids</b>	<b>Number of lots</b>	<b>Total Price</b>
Round 1	9	£450k
Round 2	7	£700k
<b>Standard supplementary bids</b>		
Supplementary bid 1	9	£850k
Supplementary bid 2	7	£725k

## Determining the winning bids

- The winning combination is the combination of valid bids with the greatest total value
- Assume for simplicity that the “other bidders” are always part of the winning combination
  - the feasible combinations of Kenny and Louise’s bids must have a total eligibility less than or equal to 21 since “other bidders” eligibility is 16
  - Hence the feasible combinations of Kenny and Louise’s bids are:

Paired lots (Kenny)	Unpaired lots (Louise)	Total value bid	Total eligibility
0	7	£725k	7
0	9	£850k	9
6	0	£1300k	12
6	7	£2025k	19
<b>6</b>	<b>9</b>	<b>£2150k</b>	<b>21</b>
7	0	£1400k	14
7	7	£2125k	21
8	0	£1500k	16

## Determining the winning bids

- If Louise had not submitted the supplementary bid for 9 unpaired lots at £850k she would have only won 7 lots instead of 9 lots.

Paired lots (Kenny)	Unpaired lots (Louise)	Total value bid	Total eligibility
0	7	£725k	7
0	9	£850k	9
6	0	£1300k	12
6	7	£2025k	19
<b>6</b>	<b>9</b>	<b>£2150k</b>	<b>21</b>
7	0	£1400k	14
<b>7</b>	<b>7</b>	<b>£2125k</b>	<b>21</b>
8	0	£1500k	16

Total value bid	Total eligibility
£725k	7
£450k	9
£1300k	12
£2025k	19
£1750k	21
£1400k	14
<b>£2125k</b>	<b>21</b>
£1500k	16

## Split supplementary bids

- Louise is able to make split supplementary bids in addition to her standard supplementary bids
  - Each split bid must correspond to a standard supplementary bid she has submitted
  - Louise can bid an amount less than or equal to the corresponding standard supplementary bid
  - An additional guard block will be included in the upper unpaired area in the event of a split award. This guard block must be included with the split supplementary bid
- Taking Louise's standard supplementary bid for 9 unpaired lots as an example
  - £850k is the maximum Louise can bid for any corresponding split supplementary bid
  - To allow for extra guard block Louise's bid must be for equivalent of 10 lots in total
  - Louise can bid on the following options (but does not have to bid on any or all of them):
    - 5 lots in one area and 5 in the other
    - 4 lots in one area and 6 in the other
    - 3 lots in one area and 7 in the other
    - 2 lots in one area and 8 in the other
- Split supplementary bids are considered alongside primary round bids and standard supplementary bids when the winning combination of bids is determined



## Assignment stage – overview

- By the end of the principal stage we will know:
  - who the winning bidders are
  - how much spectrum of each type they have won
  - the base price that each of them will have to pay
- But we won't know which specific frequencies in the 2.6 GHz band they each should be assigned
- **The purpose of the assignment stage is to allow winning bidders to express any preference they might have for specific frequencies in the 2.6GHz band**
- They do this by submitting 'top-up' bids for particular frequency ranges
- **Winning bidders will only be allowed to bid for frequency ranges that are compatible with all bidders receiving contiguous spectrum** (or contiguous spectrum in each sub-band in the case of any winning split supplementary bids)


## Assignment stage - example

- Assume that Louise made a split supplementary bid for equivalent of 3 + 7 unpaired lots and that this was one of the winning bids in the principal stage
- In the example below there are only two options available which give every bidder contiguous spectrum – Louise’s award is split into two but otherwise contiguous
- Each option has 7 lots in the centre area and 3 in the upper area
  - Block 24 is always awarded as a guard block to the uppermost assignment in the centre area

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Paired lots											Other bidders					Louise							Paired lots					Louise									
Paired lots											Louise							Other bidders					Paired lots					Louise									

 or  lot awarded as a guard block

 lots awarded to Louise

 lots awarded to "other bidders"

## Assignment stage – example

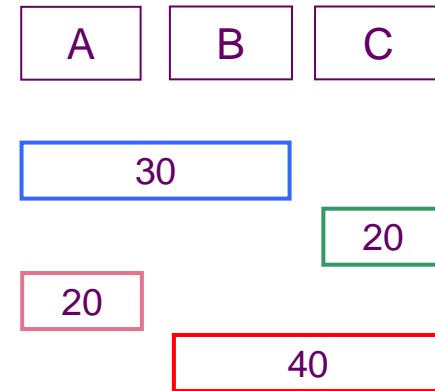
- Louise makes the following top-up bids
  - £50k for option 1
  - £0 for option 2
- “Other bidders” top-up bids collectively equal
  - £0 for option 1
  - £30k for option 2
- Option 1 is the winning assignment option as the total value of top-up bids is highest
- Actual top-up **prices** are calculated on a second price basis
  - In this case Louise would have to pay an additional £30k to win her preferred frequencies
- The winning bidders pay the total of the base price and the top-up price for their assignment

## 'Second-price' rule – illustration

- Assume combinatorial auction with three lots - A, B and C
- Assume 4 bidders – Blue, Green, Pink and Red

- Bids

- Blue            30 for A+B
- Green           20 for C
- Pink            20 for A
- Red             40 for B+C



- Maximising value - valid combinations

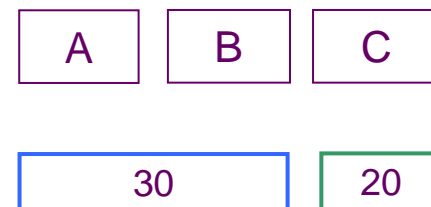
- 1) **B** (A+B) & **G** (C) – total of 30+20=50
- 2) **P** (A) & **R** (B+C) – total of 20+40=60
- 3) **P** (A) & **G** (C) – total of 20+20=40

- Winning combination is 2) for a total of 60



## 'Second-price' rule – illustration

- 'Second price' in a combinatorial context
  - Lowest prices for each winning bidder such that no individual losing bidder or coalition of losing bidders has made a valid combination of bids of higher total value
  - Second prices determined for each bidder, not per lot
- We can reduce the price paid by each winning bidder, Pink or Red, and still get
  - A total price equal to the second highest combination (50)
  - No single losing bidder happy to pay more for either of the two packages (no two bidders have bid for the same package)
- These are the opportunity costs of the winning bids
- We can reduce the price paid by Pink from 20 to 10
  - Total paid =  $10+40 = 50$
- We can reduce the price paid by Red from 40 to 30
  - Total paid =  $20+30 = 50$



## 'Second-price' rule – illustration

- However you cannot reduce the price paid by both to those levels at the same time and still get a total price equal to the second highest combination (50)
- If Pink paid the reduced price of 10 and Red paid the reduced price of 30, the total paid would be 40
  - But Blue and Green would be happy to pay more – their bids add up to 50
- We have two examples of solutions that minimise total payments
  - How do we identify a unique set of second prices?



## ‘Second-price’ rule – illustration

- Criteria for uniqueness
  - Set of prices such that the sum of squares of the difference between winning bidders prices and their opportunity cost is minimised
- Here, total payments minimised to 50 and sum of squares minimised when
  - Pink pays 15
  - Red pays 35
- In this case the sum of squares is  
 $[Pink\ price - Pink\ opportunity\ cost]^2 + [Red\ price - Red\ opportunity\ cost]^2$   
 $[15 - 10]^2 + [35 - 30]^2 = 50$
- Other solutions that minimise total payments to 50 do not minimise this sum of squares
  - Case where Pink pays 10 and Red pays 40  
 $[10 - 10]^2 + [40 - 30]^2 = 100$
  - Case where Pink pays 20 and Red pays 30  
 $[20 - 10]^2 + [30 - 30]^2 = 100$

**Any questions?**