



National Audit Office

Report

by the Comptroller
and Auditor General

Ofcom

4G radio spectrum auction: lessons learned

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4G radio spectrum auction: lessons learned

Report by the Comptroller and Auditor General

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Amyas Morse
Comptroller and Auditor General
National Audit Office

6 March 2014

This report examines whether the 4G auction achieved Ofcom's two main objectives of maintaining a competitive market and efficient allocation of the spectrum.

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Key facts

83m

mobile connections
in 2012

£20bn

Ofcom's estimate
of consumer
benefits expected
from the auction

£2.4bn

proceeds raised
from the auction

800 MHz
and 2.6 GHz

spectrum being auctioned

250 MHz

of bandwidth available at the auction

70 per cent

increase in spectrum in use following the auction

7

bidders in the auction

5

winners of spectrum in the auction

Summary

Introduction

1 In 2013, the Office of Communications (Ofcom) auctioned licences to use radio spectrum to wholesale telecommunications service providers. The licences did not specify that they had to be used to provide a particular service, but the spectrum is suited for high-speed mobile data services. The spectrum sold in 2013 provided a significant increase over the spectrum already in use and raised proceeds of £2.4 billion. The winning bidders, type of spectrum awarded and prices paid are set out in **Figure 1**.

2 This was the first major sale of radio spectrum in the UK in over ten years and allows much faster mobile communications technology (often referred to as 4G). Ofcom expects this will provide benefits for consumers estimated at £20 billion. Ofcom's main objectives in the auction were to:

- **maintain a competitive market** by having at least four national wholesale providers, each with an adequate holding of radio spectrum; and
- subject to the above objective, **achieve an economically efficient allocation of spectrum** to bidders who valued the spectrum the most and, by implication, could be expected to make best use of it.

Figure 1
Auction outcome

Winner	800 MHz (%)	2.6 GHz (%)	Price paid (£m)
EE	17	38	589
Niche (BT) (new entrant)	0	27	201
O2	33	0	550
Three	17	0	225
Vodafone	33	35	803
Total	100	100	2,368

Note

¹ O2 800 MHz licence includes a coverage obligation.

Source: Ofcom

3 This report sets out the results of our review of the outcome of the auction. As other public assets may be sold using similar auction techniques, we have also set out a number of high-level lessons for future sales of public assets. Although maximising proceeds for the taxpayer was not an objective, we compared the proceeds raised in this auction with proceeds raised in recent spectrum auctions elsewhere in Europe.

Maintain a competitive market

4 Ofcom achieved this objective. The four existing national wholesalers were all allocated at least the amount of spectrum that Ofcom had judged to be the minimum required to ensure their medium-term viability. A new entrant, Niche (BT), was also allocated a substantial holding of spectrum. However, only EE and Vodafone have enough adjacent spectrum to offer advanced 4G services with higher download speeds in future, with EE having the largest amount of spectrum in total. Ofcom also included a national coverage obligation by 2017 on one package of spectrum, which O2 won. Both O2 and Vodafone, who share their infrastructure networks such as transmission masts, announced that they expect to be able to meet the national coverage obligation by 2015, two years earlier than required.

Efficient allocation

5 We cannot yet conclude that the outcome of the auction was economically efficient. The main reasons for this are as follows:

- During the first stage of bidding, the auction rules allowed bidders to make bids knowing these were unlikely to be winning bids, helping to disguise their real intentions. Our analysis indicates both EE and Three did this during the first round of bidding, although not in the final round. This may reduce the value of the first stage of bidding, which was intended to tell each bidder about the values that other bidders were likely to place on the spectrum being offered.
- Our evaluation of Three's bidding strategy suggests that it was designed to ensure that Three never paid more than the reserve price for spectrum packages that had been reserved for it or new entrants to the market. Three knew early on in the auction that it was the only bidder for the reserved spectrum. In our opinion it is very unlikely that the reserve price was equal to its true value to Three's business.
- The auction design will only guarantee an economically efficient outcome if all participants in the auction bid the full value to their businesses of the spectrum they wanted. Based on our analysis, at least two bidders appeared to be subject to budget constraints which may have prevented them from achieving all of their objectives in the auction. This meant that they sought to limit the amount they would be required to pay for spectrum in the auction and that they were not necessarily always bidding the full value of the spectrum to their businesses.

6 Whether or not the auction succeeded in allocating spectrum to those who can make best use of it will only start to become apparent as the spectrum is brought into use by the winning bidders. As one of the conditions of the licences awarded in the auction, Ofcom can monitor operators' use of the spectrum and operators themselves can now buy and sell spectrum to match their business requirements.

Proceeds compared with other auctions

7 Ofcom has statutory obligations to citizens and consumers and had no objective to achieve any particular level of proceeds. However, we compared the proceeds achieved with those obtained in other European 4G auctions. After adjusting for population sizes, proceeds were within the range achieved in other European auctions. Ofcom's consultants, The Smith Institute, calculated that the proceeds were £159 million lower than they would have been had the radio spectrum won by Three not been reserved for a particular type of bidder.¹

Recommendations for Ofcom and wider lessons

8 We have identified a number of recommendations for Ofcom when conducting future radio spectrum auctions. Ofcom's management of the auction contained elements of good practice which other public sector organisations may wish to consider when undertaking asset sales. These wider lessons are summarised in **Figure 2** overleaf.

9 The structure of wholesale and final consumer markets for mobile telecommunications services is changing. Mobile services are increasingly being offered in packages with other services, such as broadband, fixed-line telephones and pay TV. Mobile services offered by a combination of Wi-Fi and fixed line broadband offer an alternative means of delivery, typically with a different price structure, from current mobile services.

Ofcom should therefore conduct a review of the competitive operation of mobile telecommunications markets before offering further spectrum for auction.

10 Ofcom plans to monitor whether each mobile operator is making full use of the spectrum allocated to it and **should also monitor whether the £20 billion of expected consumer benefits from 4G services are being realised.**

11 **Ofcom should select designs for future auctions that take account of the circumstances of likely bidders**, such as the likelihood that they will be subject to budget constraints. In designing future auctions, Ofcom should also try to make the design no more complex than is necessary to meet its objectives. Ofcom should also give bidders reasonable certainty on how the likely outcomes of the auction would relate to their individual bidding strategies.

¹ Assuming that bidders would have bid in exactly the same way had spectrum not been reserved for a new entrant.

Figure 2

Wider lessons

Planning

- Ahead of any sale, conduct a thorough analysis of the market and how it may develop. Ofcom analysed the market before the auction and identified the need to maintain competition among at least four national wholesalers.
- Set clear objectives in the knowledge that they may conflict and need to be prioritised. Ofcom prioritised its objective to maintain a competitive market.
- Conduct a thorough options analysis of available sale methods and select the method that will best achieve the prioritised sale objectives. The sale of radio spectrum by auction has a long history but Ofcom considered a number of changes designed to ensure it met its objectives.

Design of the auction or other method of sale

- Consult widely with potential bidders and allow time for trial runs before the sale. Ofcom took external professional advice and consulted with potential bidders ahead of the auction.
- Understand the financial positions of the bidders involved and, if possible, consider this when designing the auction. In the 4G auction, some bidders appear to have been budget constrained, potentially limiting the efficiency of the auction.
- Consider the balance between the timing of a sale (for example, the availability of finance to potential bidders) and the wider economic benefits from holding a sale sooner rather than later. Ofcom was aware that any delay in holding this auction would also delay the significant benefits for consumers it expected from the launch of 4G services.
- Ensure that the auction design is proportionate to what is trying to be achieved and avoid complexities that may confuse or deter bidders. In this auction, some bidders felt that the rules were overly complicated.

Post-sale

- Encourage transparency wherever possible by publishing full details of the auction bidding and outcomes. Ofcom has published full data on the outcome of the auction.
- Monitor and evaluate whether the expected long-term and wider benefits flowing from the sale are achieved. Ofcom intends to monitor usage of the spectrum released in this auction and should also assess whether the expected consumer benefits are being achieved.

Source: National Audit Office analysis

Part One

Background

1.1 There were 83 million mobile connections in the UK in 2012. Most people now use a mobile phone and, increasingly, mobile internet services. The introduction of faster 4G services is expected to provide benefits to consumers which Ofcom has estimated at some £20 billion. This part of the report:

- explains what radio spectrum is;
- sets out the background to the 4G auction; and
- summarises Ofcom's objectives for the auction.

What is radio spectrum?

1.2 Mobile phones and other similar devices use ultra high frequency (UHF) radio waves to carry signals to and from mobile devices. Radio waves are part of the electromagnetic spectrum and can be modified to carry information, allowing people to communicate without the need for wires.

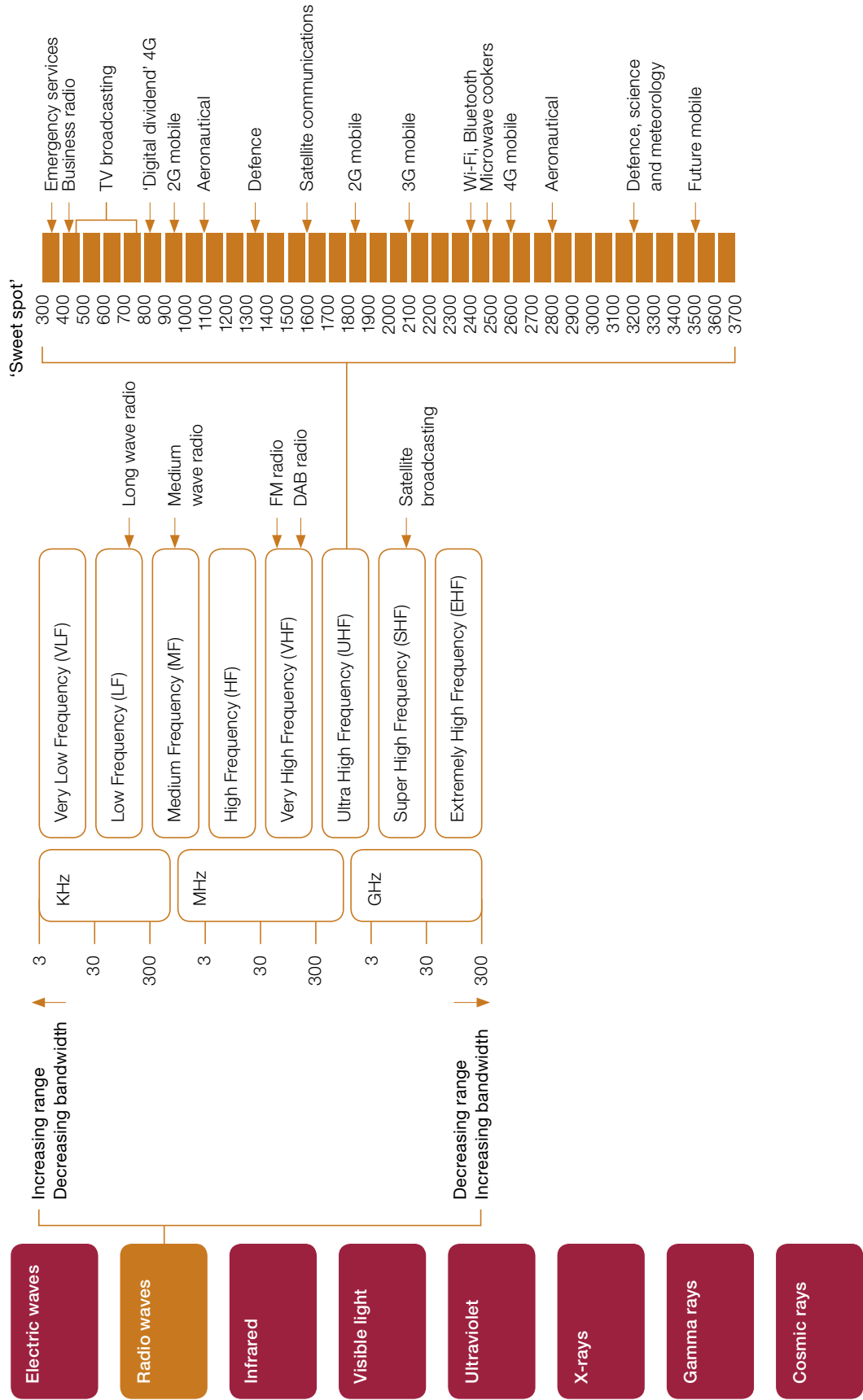
1.3 Radio waves are described by the number of waves transmitted per second, which is known as the frequency. Within the UHF band (**Figure 3** overleaf) there is a 'sweet spot' between 300 MHz and 3 GHz which is suitable for many commercial applications.

Background to the auction

1.4 The term '4G' refers to different types of technologies which allow faster transmission of data and enable services, such as video, to be used over a mobile connection. However, 4G services need much greater amounts of bandwidth than earlier 2G and 3G services.² A minimum of 2 x 5 MHz of spectrum is needed to offer a basic 4G service which would only offer relatively low speeds for data transmission. A good 4G service can be provided with 2 x 10 MHz of spectrum. Future 4G advanced services, which will offer even higher data transmission speeds, will require at least 2 x 20 MHz of spectrum.

² The quantity of spectrum allocated to an individual operator is called the bandwidth and is also measured in MHz. For example, Vodafone holds a licence over frequencies in the range of 801 to 811 MHz and this is referred to as 10 MHz of spectrum.

Figure 3
Spectrum usage



Source: Analysys Mason, 2012, based on an earlier version by Ofcom and PwC

1.5 The Radiocommunications Agency ran the auction for licences in the 3G auction in 2000. Five licences were awarded and the auction raised a total of £22.5 billion. Ofcom started consulting on releasing spectrum for 4G in 2006. **Figure 4** outlines the key dates.

1.6 In January 2009, the government published the conclusions of a review of digital communications (the *Digital Britain Final Report*) which set out a series of actions to maximise the opportunities for the UK in the digital age.³ The report also identified a complex set of challenges that were hindering the release of spectrum for next generation broadband services and appointed an independent spectrum broker to examine possible solutions. In December 2010, the government issued a 'direction' to Ofcom which included requirements for it to:

- assess likely future competition in markets for the provision of mobile electronic communication services after any award of 800 MHz and 2.6 GHz spectrum; and
- hold an auction of the 800 MHz and 2.6 GHz bands as soon as reasonably practicable after concluding the competition assessment.

Figure 4 Timeline

2006	Ofcom proposes sale of radio spectrum suitable for 4G services
2008	Ofcom launches auction of 2.6 GHz spectrum suitable for 4G services Two mobile operators launch a legal challenge to the auction; Ofcom subsequently withdrew its decision
2009	Government review of future of digital communications published Ofcom proposes to liberalise 900 MHz spectrum for 3G use and plans for auction to take place in 2010
2010	T-Mobile and Orange merge to form Everything Everywhere (EE) The government directs Ofcom to hold a combined auction of 800 MHz and 2.6 GHz spectrum
2011	Ofcom begins consultations on the auction Some operators raised concerns, which could have resulted in legal challenge. Ultimately, however, no legal challenge was filed in the courts European Commission announces that parts of the radio spectrum are to be liberalised by the end of 2011
2012	Ofcom launches consultation on European Commission announcement Government and mobile operators reach agreement on the earlier provision of 4G services allowing Ofcom to confirm the details and timing of the auction
2013	4G auction held

Source: National Audit Office analysis

3 Department for Business, Innovation & Skills, *Digital Britain Final Report*, Cm 7650, June 2009.

1.7 Ofcom's first consultation on the combined auction in 2011 proposed to liberalise the existing holdings of 900 and 1800 MHz spectrum to allow advanced 4G mobile services as soon as technical conditions could be agreed in Europe. When Ofcom agreed to a proposal from EE to launch 4G services early, several other operators threatened legal action on the grounds that EE would have an unfair competitive advantage. The operators agreed to withdraw the threat of legal action when the government agreed in July 2012 to fund the earlier clearance of 800 MHz spectrum, which allowed it to be brought into use, and allowed other operators an opportunity to launch rival 4G services sooner than would otherwise be the case.

Spectrum made available

1.8 The 800 MHz and 2.6 GHz bands made available comprised 250 MHz of mobile spectrum (**Figure 5**). This was equivalent to over 70 per cent of the mobile spectrum already in use and 80 per cent of that awarded through the 3G auction in 2000. Ofcom did not specify which type of services needed to be provided nor by what technology. However, the spectrum offered is particularly suited for 4G high-speed mobile data services.

1.9 The 4G auction would enable mobile operators to meet a significant growth in demand for mobile data. This is being fuelled by growth in the take-up of smart phones and tablets. These devices offer new services which have appeared since 2000, such as video streaming, social networking and mobile gaming, as well as applications such as messaging and email.

Figure 5

Spectrum and bandwidth lots available for auction

Spectrum	Type	Total bandwidth available	Lots of bandwidth	Number of lots
800 MHz	Paired	60	2 x 5 MHz	4
800 MHz (with universal coverage obligation)	Paired		2 x 10 MHz	1
2.6 GHz	Concurrent	60 ¹	2 x 10 MHz 2 x 20 MHz	10
2.6 GHz	Unpaired	50 ²	5 MHz	9
2.6 GHz	Paired	140	2 x 5 MHz	14

Notes

1 Total low power, concurrent and paired spectrum auctioned was capped at 140 MHz.

2 This included 5 MHz of spectrum automatically awarded as it has restricted usage.

Source: Ofcom presentation of UK's 800 MHz and 2.6 GHz auction

1.10 However, the structure of both wholesale and final consumer markets for mobile telecommunications services is changing. Wireless broadband services are increasingly being offered in packages with other services, such as broadband, fixed-line telephones and pay TV. Mobile services offered by a combination of Wi-Fi and fixed-line broadband offer an alternative means of delivery, typically with a different price structure, from current mobile services.

1.11 Lower frequency spectrum (800 or 900 MHz) is considered by mobile operators to be more valuable, as it can carry signals that travel further and are better able to penetrate the interiors of buildings. However, higher frequency spectrum at 2.6 GHz offers more capacity. Spectrum at 1,800 MHz can offer an acceptable compromise between building penetration and capacity as long as an operator has sufficient spectrum and a dense enough network of transmission masts.

1.12 The lower frequency 800 MHz band is part of the 'digital dividend', which was freed up as the UK switched from analogue to digital TV. The digital switchover, which helped clear the 800 MHz spectrum, was completed under budget and ahead of schedule. The combination of low and high frequency spectrum creates the potential for next generation mobile broadband services to be widely available across the UK. At the same time this will increase the capacity to cope with significant demand, even in urban centres.

Existing spectrum holdings and market share

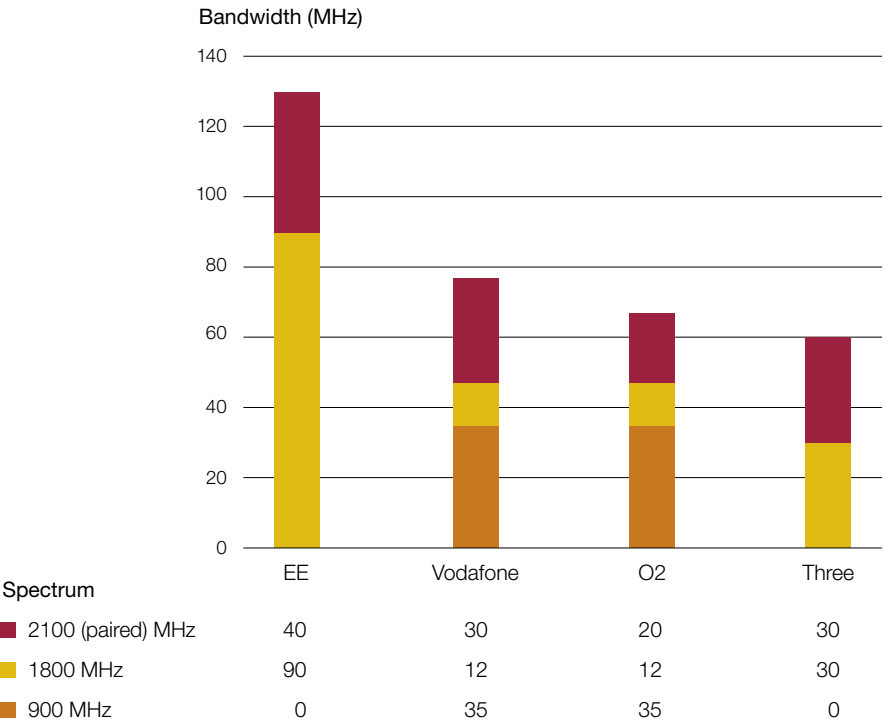
1.13 In January 2010, Deutsche Telekom (T-Mobile) and France Telecom (Orange) announced proposals to merge their UK mobile services operators to form Everything Everywhere (EE). The European Commission approved the merger in March 2010 with certain conditions. One of the conditions was that EE had to relinquish a quarter of its combined holdings of 1,800 MHz spectrum by September 2015. Just before the 4G auction, EE sold this spectrum to Three for an undisclosed sum.

1.14 In 2013, the UK had four wholesale mobile phone operators. EE held the most spectrum in terms of bandwidth, but Vodafone and O2 had more variety in the types of spectrum they hold (**Figure 6** overleaf).

1.15 After the merger, EE in 2010 also had the largest customer base and revenues of the four wholesale mobile operators. Three is the smallest operator in terms of subscriptions and revenues (**Figure 7** on page 15). O2, Vodafone, EE and Three, have established joint ventures that provide some of the infrastructure needed to deliver mobile services. While the firms share assets, such as transmission masts and antennae, they do not share their radio spectrum and operate it independently.

Figure 6
Spectrum holdings by the four main operators before the auction

EE held the most spectrum in terms of bandwidth



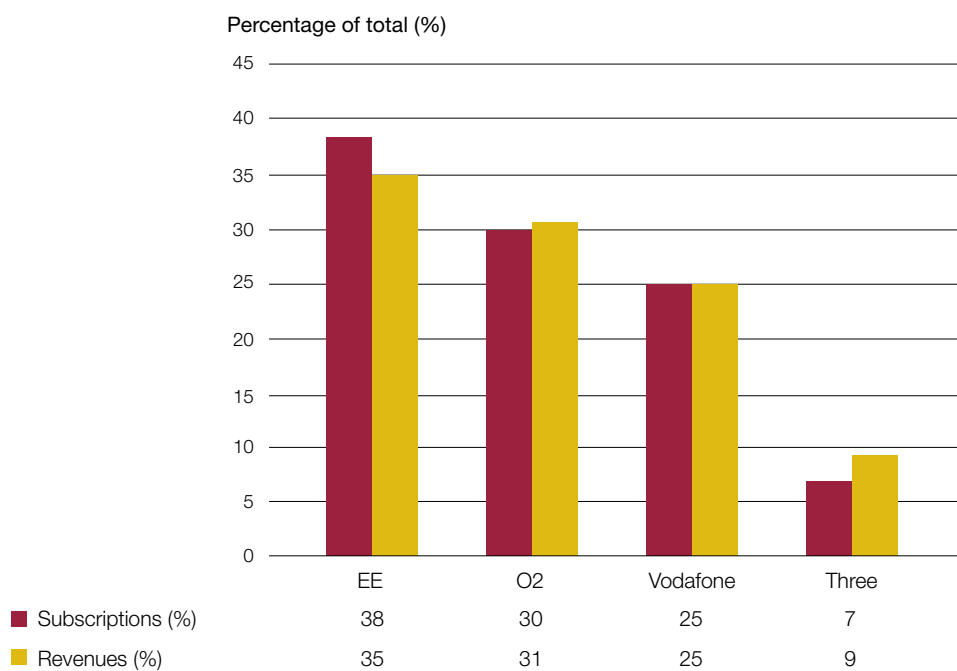
Note
1 Numbers are bandwidth of each type of spectrum holding.

Source: Ofcom presentation of UK's 800 MHz and 2.6 GHz auction

Figure 7

Market share by operator

EE in 2010 had the largest customer base and revenues of the four wholesale mobile operators



Source: Ofcom communications market report 2011

Ofcom's aim and objectives

1.16 The Department for Culture, Media & Sport has overall policy responsibility for telecommunications including mobile communications and spectrum management. It has an objective to support the introduction of 4G mobile communications to the UK. In the UK, private sector holdings of spectrum are regulated by Ofcom.

1.17 Ofcom put particular weight on its duties to promote the interests of citizens and consumers, where appropriate by promoting competition. It had no responsibility to achieve any particular level of proceeds. Ofcom also considered that its duties to secure optimal use of spectrum, promote innovation and ensure the availability of a wide range of electronic communications services throughout the UK were particularly significant. Its two main objectives for the auction were:

- to achieve a market structure where there remained at least four national wholesalers of mobile services, each with an adequate holding of spectrum to remain viable in the medium term; and
- subject to that objective, to achieve an economically efficient allocation of the spectrum being auctioned, in the sense that spectrum was awarded to the operators able to best use it.

1.18 Before the auction, Ofcom made all the spectrum, the legacy 900 and 1,800 MHz as well as that being offered in the auction, tradeable. This was an important potential mitigation if the auction did not result in an efficient allocation. Any subsequent spectrum trades would be subject to review by the competition authorities.

Consumer benefits

1.19 Ofcom has stated that the adoption of 4G technology could provide an estimated £20 billion benefit to consumers. While Ofcom has in place measures to monitor providers' use of the licences awarded, it has not yet developed an evaluation framework to assess progress in realising the consumer benefits.

Part Two

Design and outcome of the auction

2.1 This part of the report considers the design and outcome of the auction in terms of whether:

- each stage of the auction played out as Ofcom intended;
- the key objectives of maintaining a competitive market and allocating spectrum efficiently were achieved; and
- proceeds were inline with other European auctions.

Design of the auction

2.2 Ofcom engaged specialist and academic advisers and consulted publicly on the design of the auction. Such a significant level of engagement and planning on the auction was welcomed by the main bidders.

2.3 During planning, Ofcom considered the current market structure and holdings of spectrum and what operators would need to be a credible competitor in the 4G market. Although there were four operators holding spectrum licences, only three operators owned what Ofcom judged was a credible portfolio of spectrum for the provision of future mobile data services. Ofcom concluded that without intervention in the auction the smallest operator (Three) or a new entrant might not acquire the spectrum it needed to be an effective constraint on its rivals.

2.4 Ofcom chose an auction format that was designed to:

- maintain a competitive market by including minimum and maximum amounts of spectrum a bidder was allowed to win, depending on their existing spectrum holdings; and
- assist an efficient allocation of spectrum, by putting in place incentives for bidders to bid their true valuations of the spectrum on offer.

2.5 Further information on the auction design is at Appendix One. Bidders considered that Ofcom provided sufficient information for them to understand the rules and that Ofcom had explained them clearly. Ofcom also issued guidance documentation, arranged mock auctions and held a seminar in November 2012 for the potential bidders.

Outcome of the auction

2.6 There were four stages to the auction: opt-in stage, clock stage, supplementary stage and assignment stage (**Figure 8**).

Opt-in stage

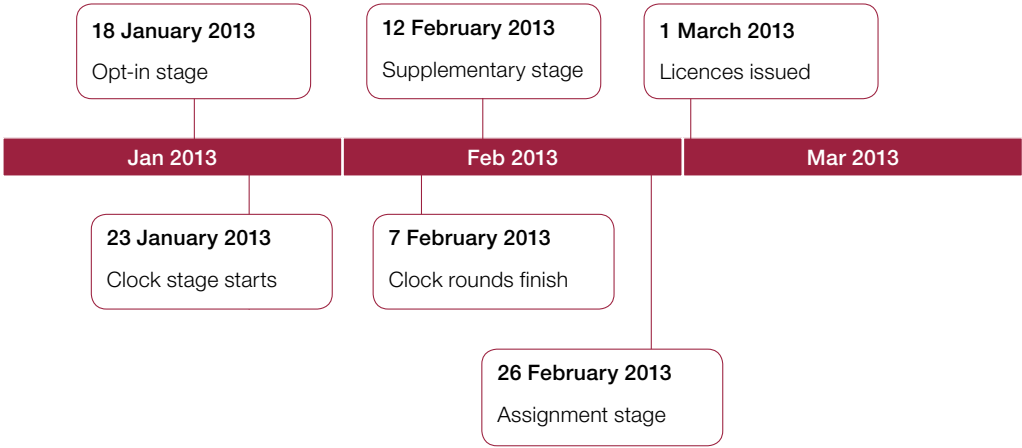
2.7 The opt-in stage took place on 18 January and bidders could signal their interest in the spectrum reserved for the smallest operator (Three) or new entrants to the market. However, Three was the only bidder and was therefore guaranteed to win one of the reserved packages of spectrum.

Clock stage

2.8 The clock stage started on 23 January. It was designed to allow bidders to express preferences for spectrum packages at various prices and to give all bidders information about the demand for and values being placed on the spectrum offered.

2.9 The clock stage ran smoothly and bidders complimented Ofcom's administration of the auction process. Bidders switched preferences for packages as Ofcom intended and demand for packages reduced over time, until demand met supply.

Figure 8
Auction timeline



Source: National Audit Office analysis

Supplementary stage

2.10 The supplementary stage took place on 12 February with a total of 277 package bids submitted by seven bidders. What bidders could bid for in the supplementary stage was influenced by what they bid for in the clock stage.

2.11 Vodafone made the most of the flexibility in the supplementary stage and submitted 94 bids. Our analysis shows Vodafone's bids during the clock stage and supplementary stage demonstrated an interest in 2.6 GHz if the price was low enough. It submitted supplementary bids on all the packages on which it had bid in the clock stage indicating it was truthful in the clock stage.

Final outcome

2.12 Out of the seven bidders, five won spectrum allocations: EE, Vodafone, O2, Niche (BT), Three. **Figure 9** sets out the spectrum won by each bidder and the price paid.

Figure 9

Final spectrum awarded and prices paid by bidders

Winner	800 MHz	2.6 GHz	Price (£m)
EE	10	70	589
Niche (BT)	0	50	201
O2	20	0	550
Three	10	0	225
Vodafone	20	65	803
Total	60	185	2,368

Notes

- 1 Two bidders, HKT (UK) Company and MCC Telecom Ltd, did not win spectrum.
- 2 We have presented the amount of bandwidth won in both 800 MHz and 2.6 GHz spectrum by the winning bidder.
- 3 An additional 5 MHz of 2.6 GHz spectrum was automatically awarded as it has restricted usage.

Source: Ofcom

2.13 Ofcom imposed a 98 per cent national coverage obligation on one package of 800 MHz spectrum, which was won by O2. The obligation was higher than the existing 3G coverage levels and had to be achieved by 2017. Both O2 and Vodafone, who have formed a joint venture to manage their networks of transmission masts, have announced that they expect to offer the required level of national coverage by 2015, two years earlier than the obligation.

2.14 Ofcom published the bidding data for the whole auction aiding transparency. This is the first time worldwide that this data has been made publicly available for a 4G auction. Overall, bidders were happy with their allocations but some bidders did not expect to win the spectrum they received and the final outcome was sensitive to small changes in the values of final bids.

2.15 Some bidders told us that they had found the auction design excessively complex and it had been difficult to develop bidding strategies to ensure that they obtained the spectrum they desired. They had to design simulations to test possible strategies, but it was not possible to simulate all possible outcomes.

2.16 At the end of the auction the UK still has four mobile communications wholesalers. EE and Vodafone hold the majority of the spectrum and Three has the least (**Figure 10**). The one key change is that there is now a new entrant to the market Niche (BT). Post auction analysis by a bidder suggested that if O2 had bid £28 million less for the 800 MHz package or increased its combined bid by £28 million, O2 would have won two lots of 2.6 GHz.

Achieving the two key objectives

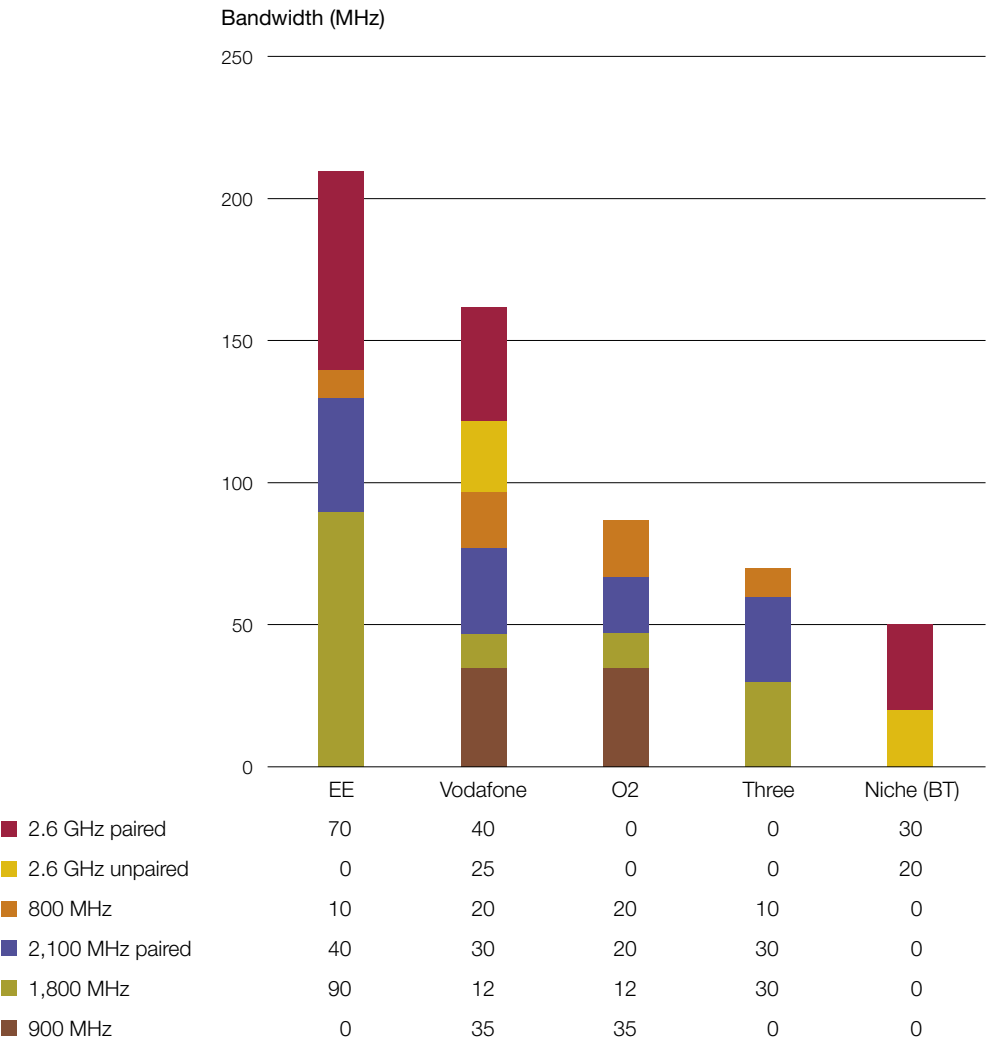
Maintaining a competitive market

2.17 Ofcom achieved its objective of maintaining at least four competing national wholesalers and gained a new entrant to the market. The four existing national wholesalers were all allocated at least the amount of spectrum that Ofcom had judged before the auction to be the minimum required to ensure their medium-term viability. However, only EE and Vodafone have enough adjacent spectrum, 2 x 20 MHz in the same band, to offer 4G advanced services with higher download speeds in future. A new entrant, Niche (BT), was also allocated a substantial holding of 2.6 GHz spectrum.

2.18 EE has two million 4G customers at January 2014. O2 and Vodafone launched 4G services in 2013 and now have 370,000 4G customers.

Figure 10
Spectrum holdings after the auction

EE and Vodafone hold the majority of the spectrum and Three has the least



Source: Ofcom

Efficient allocation of spectrum

2.19 We cannot yet provide assurance that the outcome of the auction was economically efficient. There are three reasons for this.

Two bidders hid their preferences for spectrum

2.20 During the first stage of bidding, the auction rules allowed bidders to make bids knowing that these were unlikely to be winning bids, helping to disguise their real intentions. Our analysis indicates both EE and Three did this during the first round of bidding (**Figure 11**), but not during the final round. This may have reduced the value of the first stage of bidding, which was intended to inform bidders about the values that other bidders were likely to place on the spectrum being offered.

Three aimed to secure reserve spectrum at the reserve price

2.21 In addition, our evaluation of Three's bidding strategy suggests that it was designed to ensure that Three never paid more than the reserve price for the spectrum that had been reserved for it or new entrants to the market, and for which it knew early on in the auction that it was the only bidder. In our opinion it is very unlikely that the reserve price for this capacity was equal to its true value to Three's business.

Two bidders adopted a strategy that appeared budget constrained

2.22 Under the auction rules, each winning bidder paid the price that the second highest bidder was willing to pay. This 'second-price' rule is designed to encourage truthful bidding by all bidders and ensure there is an efficient allocation of spectrum to those bidders who value it most.

Figure 11
Outcomes differed between clock and supplementary stage

Spectrum Details	800 MHz		800 MHz national coverage		2.6 GHz paired		2.6 GHz unpaired	
	Clock	Supplementary	Clock	Supplementary	Clock	Supplementary	Clock	Supplementary
EE		✓				✓	✓	
Niche (BT)					✓	✓		✓
O2			✓	✓				
Three		✓			✓			
Vodafone	✓	✓			✓	✓		✓

Source: National Audit Office analysis

2.23 However, an auction using the second-price rule is only guaranteed to be efficient if bidders provide their true valuations of the spectrum they are attempting to win. In this auction, our analysis indicated that at least two bidders appeared to be subject to budget constraints which meant that they sought to limit the amount they would be required to pay for spectrum in the auction. These budget constraints meant that they were not necessarily bidding the full value of the spectrum to their businesses. This may have prevented them from achieving all their objectives in the auction.

Proceeds

2.24 Spectrum has a substantial economic value. Telecommunications services based on spectrum are purchased not just directly by customers, but also form a key input into nearly every sector of a modern economy. The value of the spectrum being auctioned lies primarily in the consumer benefits, which Ofcom has estimated at some £20 billion, of additional capacity and higher transmission speeds becoming widely available. Given the importance of services derived from spectrum for the wider economy, governments should try to maximise the overall benefit from the efficient use of spectrum, rather than maximising revenue from sales.

2.25 Ofcom's aim was to facilitate the efficient use of spectrum and promote competition, rather than maximising revenue. In the UK, the Communications Act 2003 defines Ofcom's general duties, which are based on European Union law and are to further the interests of consumers and, where appropriate, to promote competition.

2.26 Allocating spectrum efficiently means selling it to those able to create greatest overall benefit with it. Provided that competition between spectrum licensees is effective, efficient allocation can usually be achieved by licensing spectrum to whoever values it most. Auctions can therefore provide a useful tool to achieve efficient allocation, which may also generate significant sums for the taxpayer as a by-product.

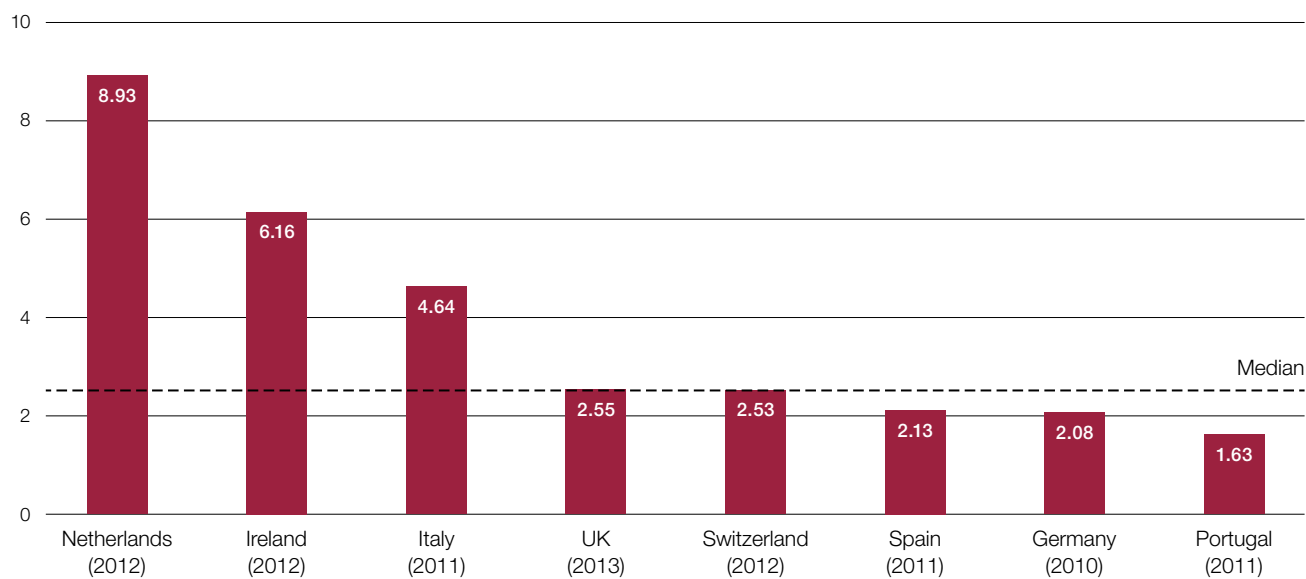
2.27 We have compared (**Figure 12** overleaf) the proceeds achieved with those obtained in other European auctions conducted during 2010 to 2012 which included spectrum in both the 800 MHz and 2.6 GHz bandwidths. After adjusting for population sizes, proceeds were within the range achieved in other European auctions.

Figure 12

Auction proceeds by country

Proceeds were in line with those achieved in other auctions

Price paid per MHz of spectrum (adjusted for population size) (£m)



Source: Based on data published by Koninklijke KPN NV (a leading telecommunications provider in the Netherlands)

Appendix One

Auction design

1 This Appendix sets out how the auction was designed to:

- maintain a competitive market;
- allocate spectrum efficiently; and
- determine the prices at which spectrum would be sold.

Maintain a competitive market

2 Ofcom conducted a competition analysis. This showed that the strength of competition in the mobile communications market depended on current and potential future mobile operators acquiring spectrum in the 4G auction. Ofcom's key objective was therefore to promote at least four credible national competitors. Ofcom put in place spectrum floors which would ensure that the auction resulted in at least four operators, each with a minimum portfolio of spectrum. Pre-auction spectrum holdings counted as well as spectrum acquired in the auction. In effect, spectrum was reserved for an operator, either Three or new entrants that did not already have a minimum portfolio. To prevent the larger mobile operators acquiring large amounts of unreserved spectrum, the auction also included caps on the total amount of spectrum each operator could hold.

3 Ofcom expected that eligible bidders for the spectrum floors would compete against each other for the reserved spectrum. Other bidders (and eligible bidders beyond their spectrum floors) would compete for the unreserved spectrum. In theory, the choice of floor would be determined by competition between two 'mini-competitions' within the overall auction.

4 Based on prices paid in previous auctions in Europe, Ofcom set a reserve price for each package of spectrum. Spectrum would not be sold if bids did not at least equal the reserve price. Ofcom considered that the 800 MHz spectrum was more valuable than the 2.6 GHz spectrum and set reserve prices for the 800 MHz spectrum at a higher proportion of estimated value than for the 2.6 GHz spectrum (**Figure 13** overleaf).

Figure 13
Spectrum floors and reserve prices

Spectrum	800 MHz	2.6 GHz	Reserve Price
Portfolio 1	2 x 5 MHz (no coverage obligation)	–	£225m
Portfolio 2	2 x 10 MHz (with coverage obligation)	–	£250m
Portfolio 3	–	2 x 20 MHz	£60m

Source: Ofcom

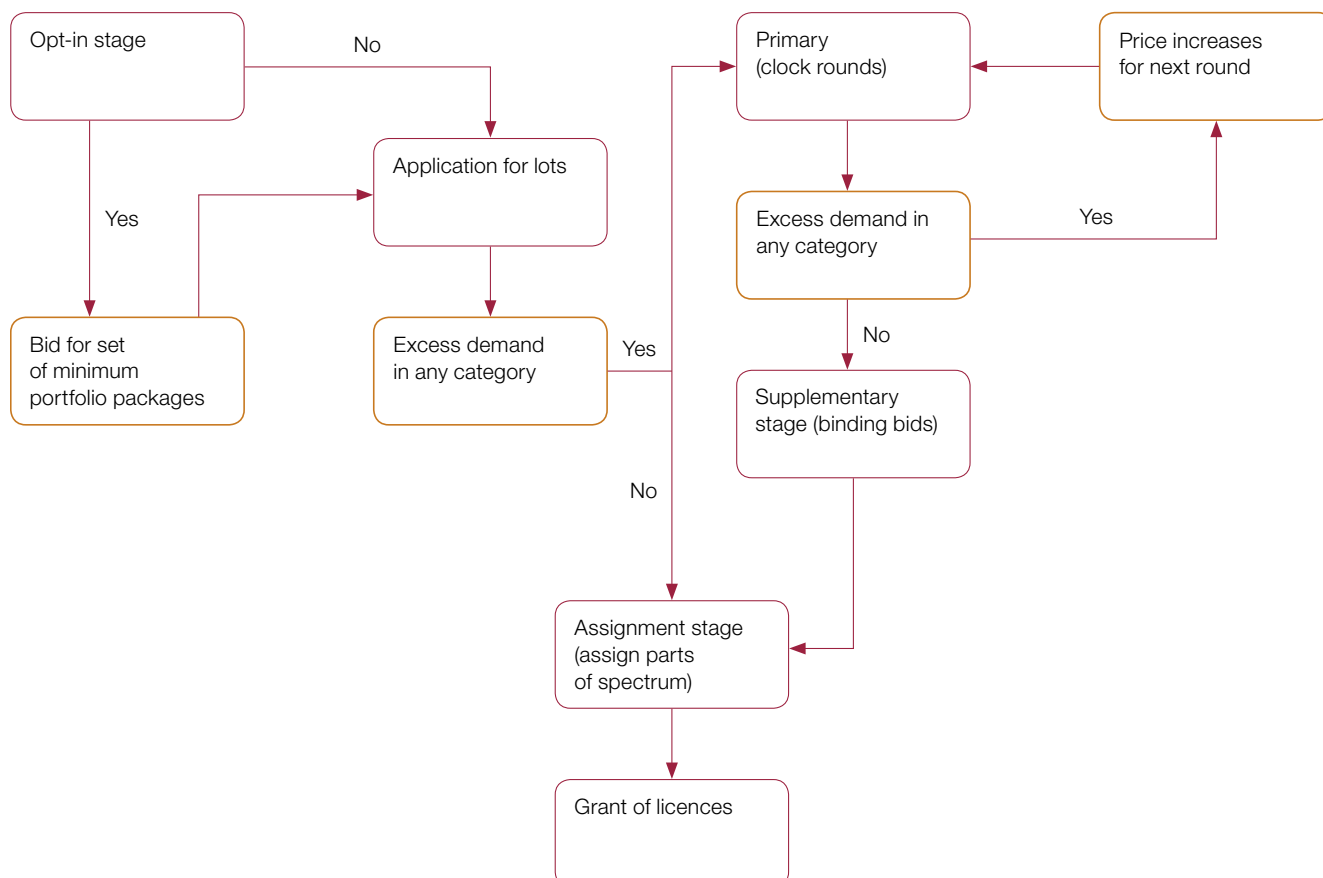
Efficient allocation of spectrum

5 In the auction, a mobile operator might want to buy a combination of 800 MHz spectrum for coverage and 2.6 GHz spectrum for capacity. In such circumstances, the value of 2.6 GHz spectrum to a bidder may depend on whether the bidder also wins 800 MHz (and vice versa). But when deciding how much to bid for 2.6 GHz spectrum, a bidder will not know whether or not it will win some 800 MHz spectrum (and vice versa). Bidders would therefore need to manage the risk of winning 2.6 GHz spectrum, but failing to win 800 MHz, at a bid above the value of 2.6 GHz spectrum on its own. As a result bids may not accurately reflect true value, which will reduce auction efficiency.

6 To enhance auction efficiency by avoiding the risk that bidders might not win spectrum they valued the highest, Ofcom decided to use a combinatorial clock auction (CCA) format for the auction (**Figure 14**). Bidders could bid for a combination of 800 MHz and 2.6 GHz in which the bidder either wins both or neither. A bid could not be split up to win 800 MHz but not 2.6 GHz (or vice versa). The CCA format had been developed by Ofcom for spectrum auctions and has been widely used internationally. Ofcom had already used it for two smaller auctions of spectrum in 2008.

Figure 14

The combinatorial clock auction process

Source: National Audit Office analysis based on NERA Economic Consulting paper, *Planning and organising a spectrum auction*

7 The auction had four stages:

- In the opt-in stage, eligible bidders (bidders other than EE, O2 or Vodafone) could elect to bid at the reserve price for a set of minimum portfolio packages.
- In the primary bid rounds, bidders made a series of single bids for combinations of one or more lots of spectrum. The auction was run on a 'clock' basis, with Ofcom raising the price for each lot by a specified amount for each round. Primary bidding continued for each spectrum type until demand for that type equalled the available spectrum. The purpose of the primary bid round was to give bidders information about the values that other bidders were placing on each type of spectrum. The bids in the clock stage were binding.
- In the supplementary bids stage, which was a single final round of sealed bids, bidders could repeat or increase the bids that they had already made. They could also make bids for different packages of spectrum, including bids that they had never submitted in the primary bid rounds. Supplementary bids were binding on bidders. Ofcom allocated spectrum to winning bids in the auction by considering all rounds of bidding in the auction.
- Further bidding in an assignment stage determined who acquired each individual band of spectrum within each different type of spectrum.

Prices to be paid by winning bidders

8 Ofcom identified the winning bids by selecting:

- at most one bid from each bidder;
- only bids for no more spectrum than was available in the auction; and
- bids which were consistent with the spectrum floors and caps it had established.

9 The price paid by each winning bidder was calculated using a 'second-price' rule (**Figure 15**). A winning bidder would pay what the second highest bidder was willing to bid. The second-price rule is designed to ensure there is an efficient allocation of spectrum to those bidders who value it most, as it is meant to encourage truthful bidding. However, this will only produce an economically efficient outcome if bidders do not have a limited budget.

10 If the price that a bidder is willing to pay is limited by a budget, even if the spectrum would be worth more to that bidder than the amount of its budget, then it will have difficulties in deciding what price to bid. It will not know with certainty the gap between the value to it of the spectrum and the price that the next highest bidder is prepared to pay. If it makes an incorrect guess, it may win less spectrum in total than it could in reality afford to buy within its budget. The effect can be to reduce the total amount that such a bidder will bid in the auction.

Figure 15**Second-price rule**

The second-price rule can be illustrated by the example of bidding in an auction house, such as Sotheby's or Christie's. Initially there can be many bidders, but eventually as the price bid rises all but one bidder will drop out and the auction will end. It follows that the price paid by the winning bidder will exceed by a small margin the highest price the losing bidder was prepared to pay before dropping out. The winning bidder need never reveal the price that it was prepared to pay, which might have been even higher.

The second-price rule is designed to encourage bidders to reveal in the auction the value which they place on the lots they bid for. Bidders know that they can never be required to pay more than they bid and will only pay the price bid by the losing bidder. The intention is that bidders should not have an incentive to reduce their bids to the level they think will be just enough to win ('shading bids') – they should not need to second guess what other bidders might do.

Source: National Audit Office analysis

Appendix Two

Our audit approach

- 1 Our report examined whether the 4G auction achieved Ofcom's two main objectives of maintaining a competitive market and efficient allocation of the spectrum.
- 2 We reviewed:
 - whether the two main objectives were met; and
 - the impact of the auction design on the outcomes.

Our evidence base

- 3 We **undertook a document review** and examined a variety of documents including Ofcom's consultation documents and academic papers on the results of the UK 4G auction.
- 4 We undertook **semi-structured interviews** with Ofcom and the winning bidders of the 4G auction, Three, O2, EE, Vodafone and Niche (BT). The interviews covered the bidding process, auction outcome and lessons learned. The interviews took place between June 2013 and February 2014.
- 5 We also sought **specialist advice** from our staff experts and from the London School of Economics on auction theory. They provided **quantitative analysis** on the auction process and also acted to challenge the study team.
- 6 The quantitative analysis considered the following:
 - The bidding process at each stage of the auction.
 - Bidding strategies employed by the bidders.
 - The final outcome and how sensitive it was to change.
- 7 The initial findings of the analysis were presented at an academic seminar to enable testing of the theory and the analytical approach.

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