Final report for UK Spectrum Policy Forum

Review of market mechanisms as applied to mobile spectrum in the UK

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10 November 2022

Ref: 8884698679-461

Contents

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1 Executive summary

This is the final report from a study carried out by Analysys Mason, together with Professor Martin Cave,[1] for techUK, on behalf of the Spectrum Policy Forum (SPF). The objective of the study has been to conduct a review of market mechanisms as applied to licensed mobile spectrum bands in the UK.

In line with the UK SPF's terms of reference for the study, 'market mechanisms' refers to use of the following:

- **Auctions**: the assignment of spectrum licences through an auction process
- **Pricing**: the levying of annual licence fees (ALFs), also referred to as administered incentive pricing (AIP)
- **Trading**: the ability for spectrum licences to be traded (and potentially leased).

This year marks the 20th anniversary of a landmark report commissioned by the UK government titled *Review of radio spectrum management*, led by Professor Martin Cave ('the Cave report'). The philosophy and actions set out in the Cave report played a key role in shaping the market-based approaches that the government and Ofcom have defined for managing access to spectrum, including licensed mobile spectrum.

Since the Cave report was published, the mobile sector in the UK has undergone significant development. Substantial changes can also be foreseen in the remainder of this decade, regarding the technologies used within the sector, demand for services and the structure of the market. The most prominent changes are likely to include further technological development (with a possible sixth generation of wireless connectivity (6G) emerging by the end of the decade), new types of networks and network providers, changes to network architecture through network densification, and the possibility of further spectrum for mobile use being considered as 6G is defined.

This study provides a timely opportunity to review the effectiveness of the three market mechanisms over the last two decades, and their appropriateness to the present, and future, environment for spectrum management.

The aim of the study has been to produce an up-to-date, independent, evidence-based reference source examining the benefits of, and issues with, the three market mechanisms as applied to licensed mobile spectrum bands in the UK. Our analysis is based on research conducted for this study, including published material (e.g. Ofcom consultations, industry responses to Ofcom consultations and third-party reports), Analysys Mason's own in-house research, together with a small number of targeted one-to-one discussions with selected companies active in the UK mobile market.

[1] Professor Cave assisted the authors in reconstructing the historical background, formulating future options and reviewing the draft report.

The draft findings of this report have also undergone independent peer review by a group of experts appointed by techUK, on behalf of the UK SPF. The peer review team unanimously and fully endorsed Analysys Mason's summary table of conclusions, which is presented in the following section. Details of the peer review team, and further information about the peer review findings are provided in Annex D. Analysys Mason would like to thank members of the peer review team for their inputs.

Following this process, further comments were gathered during an SPF Cluster 2 meeting with key stakeholders (verbally during the meeting and subsequently in writing). Analysys Mason also thanks stakeholders for these comments, which have been reviewed and considered by the Analysys Mason team in producing this final report.

Based on the conclusions from the study, the SPF is seeking to identify whether there is a case for adapting any of the market mechanisms, to inform decisions made by the government, Ofcom and legislators in determining what future generations of mobile spectrum regulation should look like.

This study concerns the application of market mechanisms for promoting the efficient use of spectrum[2] and positive outcomes for users of mobile services.[3] Whether by design or not, some of the market mechanisms may also have a wider impact (e.g. generating income for government from a scarce national asset – i.e. radio spectrum – which can in principle be used to generate wider social benefits[4]). As such, any changes to the market mechanisms may have an impact on more than just spectrum efficiency. Such considerations are beyond the scope of this study, although some stakeholders (e.g. HM Treasury) may wish to consider the incidental impacts of any changes to the market mechanisms, including those which form the basis for our recommendations.[5]

1.1 Summary of conclusions and recommendations

A high-level summary table of our key conclusions is shown in Figure 1.1.

2 'Efficient use of spectrum' in this context refers to economic and technical efficiency as well as spectrum utilisation.

3 By 'users of mobile services' we mean both individual consumers and businesses that make use of mobile services. By 'positive outcomes' we refer to the quality and price of the available mobile services.

4 For example, although this was not adopted as part of Ofcom's statutory duties under the 2003 Communications Act, the Cave report also proposed deriving full economic value from radio spectrum as a key governmental objective.

5 For example, if ALFs are removed from the currently assigned mobile bands, the government might consider whether some other form of one-off payment or taxation associated with use of a scarce national asset is appropriate. In relation to such considerations, we note that non-discrimination across all commercial users of the same scarce national asset (for example, DTT multiplex providers, private 5G network providers and LEO satellite operators) is likely to be an important principle.

Figure 1.1: Summary of key conclusions [Source: Analysys Mason, 2022]

Question		Trading	Auctions	Pricing
Does the basic philosophy articulated in the Cave report still support use of a market mechanism of this form?		Yes	Yes	No
Is the market mechanism approach and current implementation of that approach optimal in terms of both promoting spectrum efficiency and avoiding undue problems/risks?		No	No	No
Are there possible alternative options that might lead to better outcomes, in relation to ...	... the market mechanism approach?	No	No	Yes
	... the way the market mechanism approach is currently implemented?	Yes	Yes	Yes

Further explanation for our key findings in this summary table is provided below.

- The mobile market (and the telecommunications market more broadly) has changed significantly since the Cave report was written, and further, potentially disruptive, changes can be foreseen in the remainder of this decade.
  - Regarding ***trading*** and ***auctions***, our view is that the fundamental economic philosophy articulated in the Cave report continues to support these market mechanisms (hence a 'yes' in the first row)
  - Regarding ***pricing***, however, we take the view that the philosophy underpinning the pricing of nationally available public mobile spectrum no longer applies (hence 'no' in the first row for pricing). Given that mobile trading is possible between mobile network operators (MNOs), and between MNOs and other third parties, our view is that pricing is not needed as an extra incentive to support economic or technical efficiency in mobile spectrum.[6]
- In the second row of the table we ask whether each market mechanism, as currently implemented, is optimal. We conclude that the answer is 'no' for all three mechanisms: this is because, in each case, we identify potential issues and concerns in relation to the promotion of economic and/or technical efficiency and/or avoiding undue problems/risks. The strength of these concerns varies. For example, the issues we identify are relatively minor for trading, but more major for auctions in the context of the type of new mobile spectrum that might become available in the remainder of this decade, particularly at higher frequencies. For pricing, we consider that the arguments for ALFs being needed to provide an extra incentive for more-efficient use are weak.
- Given that the situation is not optimal, in the third row we ask whether there are any alternative options to the overall approach for each market mechanism that might lead to better outcomes.

6 While we argue in this report that there is not clear evidence that ALFs are needed to promote efficient use of *mobile* spectrum, it is important to note that our reasoning may or may not be applicable to other spectrum bands supporting different types of usage.

- Regarding ***trading***, we answer 'no': our view is that the principle of trading is sound, and that this remains the case when taking account of possible future technological and market changes over the remainder of this decade.

- Regarding ***auctions***, we consider that alternative options (e.g. administrative assignment, shared spectrum access, dynamic spectrum access (DSA)) do exist and may be relevant (or at least form an important part of any solution) in some situations – specifically, in higher frequencies, or in bands where mobile use is permitted alongside other existing uses, or where there is expected to be some form of shared use in the future.

    - In mobile networks, higher frequencies are principally used to increase network capacity where needed (i.e. in locations where the highest portion of data traffic is generated). If not deployed to provide contiguous coverage over wide areas, there is a question over whether any future, higher frequency, mobile bands should be auctioned for mobile use on a national basis, or whether there will be greater opportunities for sharing between future mobile use and existing (or future) services allocated within those bands. Auctions of sub-national mobile licences might allow mobile use to co-exist within the same spectrum also used for other services but in geographically separate locations (or, the mobile licensed portions of spectrum might co-exist with existing use in the same geographical location, if feasible to do so).

    - For lower-frequency spectrum (e.g. bands deployed for nationwide coverage) our view is that auctions of national licences will continue to be the best approach. As such, we answer 'no' in the summary table, as we think that auctions must continue to play an important part in any future solution. We note that Ofcom's recently proposed approach to the 26GHz and 40GHz bands is different from that adopted when auctioning the most recently assigned national mobile bands (at 700MHz and 3.6GHz). Hence, Ofcom's thinking is already moving in the direction of increasing geographical utilisation of spectrum via area-defined licences for higher frequency bands. This approach also potentially provides a means of reducing scarcity in spectrum that might apply in situations where licences are only made available on a nationwide basis.

- Regarding ***AIP-based pricing***, we answer 'yes': our view is that there are alternative options which may lead to better outcomes.[7] Namely:

    - removing ALFs for existing licences, and issuing any future mobile licences (i.e. in new bands that might become available for mobile use) with indefinite terms, and

[7] Both of these alternative options are likely to lead to equivalent or better outcomes (relative to the current ALF arrangement) in terms of spectrum efficiency/utilisation and the quality and price of available mobile services.

    - considering whether societal benefits from greater access to mobile services can be realised through a 'non-cash' approach for currently licensed mobile bands, in which, for example, ALFs are replaced by MNO coverage/investment commitments that can contribute to economic growth and increased spectrum utilisation.[8,9]

- The final row asks whether there are alternative options to the way the overall market mechanism is currently implemented that might lead to better outcomes. For all three market mechanisms, we answer 'yes'.

  – Regarding ***trading***, it may be beneficial to introduce market-led leasing (i.e. the ability for MNOs to lease specific frequencies for a defined time period, rather than to make an outright trade). Local access licensing has largely addressed the disadvantages of not having a leasing framework (except where longer leases may be required or in certain edge cases, e.g. where an MNO is using the spectrum but a local user could derive greater value from it), but enabling MNOs to make leasing agreements directly with third parties would provide additional flexibility. If market-led leasing was introduced, liability arrangements between the MNO and the leaseholder would need to be carefully considered. A potential alternative to the market-led leasing approach might be for Ofcom to modify/clarify the existing local access licensing framework to achieve a similar result. That is, the MNO could be allowed to charge a fee to the local licence applicant as a condition of granting permission (in cases where the MNO would otherwise have a right not to grant permission, e.g. because it has plans to use the spectrum).[10]

  – Regarding ***auctions***, Ofcom needs to take due care when designing them, and consideration of objectives, and the design of an auction to meet the objectives of the award, will continue to be needed on a band-by-band basis as new bands are investigated for mobile use, especially where there may be a possible opportunity for sharing between mobile and other (existing or new) services in the same bands. Arguably, not all mobile spectrum auctions in the UK to date appear to have maximised spectrum efficiency, e.g. certain aspects of the 800MHz/2.6GHz auction are often cited as an example here. Shared/local licensing is also expected to become more relevant as there is a shift to higher frequencies. However, we note that Ofcom is already focused on addressing both issues relating to auction design and the incorporation of shared/local licensing, and as such there is no need for a change of approach per se.

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8 That is, a commitment from MNOs to achieve specified coverage or service quality levels, or to invest specified amounts in their networks (above and beyond the investment that would have occurred on a commercial basis). Illustrative examples of investment commitments that could contribute to economic growth are provided in Section 6.1.3.

9 We note that if government chose to replace ALFs with some other form of taxation of radio spectrum, then the viability of investment commitments alongside any such measure would need to be considered carefully (e.g. rigorous cost–benefit analysis to determine any potential investment commitment).

10 We have not sought to examine the relevant legal framework in detail, but we note that this alternative approach might, in practice, be simpler to implement if there were concerns (for example) over how liability (including criminal liability) would be dealt with in a leasing arrangement. For example, we understand that criminal liability (including a criminal breach of the Wireless Telegraphy Act) cannot be contracted away to a third party.

– Regarding ***pricing***, the answer is implicitly 'yes', given that we consider the argument for using AIP-based ALFs to provide extra incentive for more efficient use to be weak. We note that raising the level of ALFs above opportunity cost would not increase spectrum efficiency, and would risk licensees returning their spectrum to the regulator (and deterring other operators from subsequently acquiring that spectrum from the regulator).

Summary of key recommendations

- **Trading**. It may be beneficial to introduce market-led leasing, which is not currently possible for mobile spectrum.

- **Auctions**. Ofcom should continue to take due care in designing auctions and give consideration to sharing opportunities on a band-by-band basis for any new bands that might become available for public mobile services in future, especially if the public mobile use is not expected to be nationwide. New types of auction (e.g. of non-exclusive, non-nationwide licences) might be relevant. With the shift towards higher frequencies, other spectrum authorisation approaches may also be required alongside auctions. Technology-based solutions (e.g. databases) might feature in future authorisation approaches. Ofcom should consider, on a case-by-case basis, whether there is sufficient demand to justify an auction, or whether an alternative approach (such as administrative assignment via shared/local licensing) is more suitable, and the form of any technology solutions needed to manage any sharing within the band.

- **Pricing**. We identify two broad options on pricing:

  – Option 1 – remove ALFs for currently assigned mobile spectrum, and award future mobile licences as indefinite from the outset[11]
  – Option 2 – consider 'non-cash' (or hybrid) approaches for currently licensed bands, e.g. replace some or all of the ALF payments with coverage/investment commitments.

The choice between these options involves complex trade-offs. Relative to the current ALF approach:

  – Option 1
    ° does not result in any loss of spectrum efficiency and potentially offers gains if barriers to trading are reduced
    ° does not result in any loss of spectrum utilisation and potentially offers gains if there is an increase in investment
    ° does not result in any loss in terms of retail price, and potentially offers gains if prices fall.

11 Licence durations might also vary between shared and exclusive use spectrum. Our recommendation is that future auctioned licences for mobile spectrum assigned on an exclusive basis to operators could be awarded with an indefinite term, meaning that prices paid at auction would reflect the indefinite duration of the licence. However, licences for mobile use of spectrum shared with other uses might be awarded with a shorter duration (as Ofcom is doing currently) as a way of encouraging innovation and providing greater flexibility for a future change in spectrum use.

Furthermore, increased financial stability of MNOs could help to prevent a worse outcome from materialising across any of these three areas.

  - Option 2
    - does not result in any loss of spectrum efficiency
    - does not result in any loss in terms of retail price
    - results in increased investment in mobile infrastructure, leading to higher geographical utilisation of spectrum and potentially contributing to economic growth.

It is unclear whether the geographical spectrum utilisation/investment gain in Option 2 is likely to outweigh the (potentially broader but less certain) gains in Option 1. The choice between these two options would constitute an important policy decision for Ofcom and the government, which should ideally be supported by a rigorous cost–benefit analysis.

- **Timing**. The case is strong that now is the time to review, adapt and modernise all of the market mechanisms. There are changes that can be made in the short to medium term that can contribute to the promotion of spectrum efficiency, and potentially also to economic growth, as outlined above. More ambitious changes could be considered in the long term, and now is a good time to invest in long-term research into these possibilities that could, for example, deliver spectrum sharing at scale. We outline some preliminary future considerations in this regard below.

1.2 Future considerations

As the market has evolved, so too has academic discussion surrounding the assignment of spectrum for mobile use, giving rise to novel and alternative concepts of market mechanisms (such as 'depreciating licences' and 'foothold auctions'). However, these concepts are still at a nascent stage, and so it is unclear whether these solutions would be relevant for addressing the identified shortcomings of existing approaches in the UK mobile market.

In a future market, it can be envisaged that more mobile spectrum might be licensed on a shared, rather than exclusive use basis, particularly at higher frequencies, and mobile devices might operate seamlessly across frequency bands for which different licensing arrangements would apply. This type of environment might require regulatory action to change market mechanisms in line with a move away from exclusivity in spectrum use. For example, the mobile industry might be required to invest in developing appropriate technology to use shared spectrum in mobile networks, and investment in database technology could also be considered.

Actions might also be needed by regulators to ensure that incentives for efficient spectrum use were aligned across different types of use, and that any competition concerns were addressed. Through the set-aside of the 3.8–4.2GHz band for shared access use, Ofcom has already introduced a situation in which spectrum that might be of value to MNOs (on a licensed basis) and can support services that compete (to a certain extent) with those offered by MNOs is available under a licensing approach that is not subject to market mechanisms.

Given market trends and our recommendations for adapting the market mechanisms, the spectrum management landscape (for licensed mobile spectrum) may look somewhat different in the future.

- Regarding ***trading***, the shift to mobile use in higher frequency bands (alongside other market developments such as the new types of players and business models enabled by 5G and future technologies) raises the possibility of more trading in future (for example, if auctions are used to award multiple, area-specific licences, rather than a more limited number of national licences). Where licences are issued on a more localised basis for higher frequencies there may be scope for increased volumes of trades or leases at lower value, which could potentially be achieved through a more automated system involving less friction and lower transaction costs. Automated systems such as databases might also assist in the management of bands where there is sharing between incumbent and new uses of a band (for example, a band in which there is incumbent use outside of urban locations, and where mobile use is concentrated primarily in urban locations where levels of data traffic are high). We might also see more sharing between different forms of use within the same band – licensed mobile together with licence-exempt technologies, for example.

- Regarding ***auctions*** and ***pricing***, the shift to mobile use at higher frequencies (alongside other market developments) raises the possibility of innovative/dynamic pricing arrangements. For example, if licensees could agree to certain conditions (e.g. co-existence/sharing conditions, low transmission power) which enable greater co-existence and hence reduce the level of spectrum scarcity, then this could be reflected in lower pricing levels for such users, potentially on a dynamic basis.

Suggested next steps

The focus of this study has been the three market mechanisms as currently applied to licensed mobile spectrum bands in the UK. We recommend that further work could be conducted to undertake a detailed assessment of how the market mechanisms might stand up to a variety of potential future developments in the mobile market. Such potential future developments could include:

- Extensive network densification through the proliferation of small cells (particularly indoors), which may create demand for access to shared spectrum to enable new models, such as neutral-host provision or self-deployment by building owners
- The emergence of a national-scale wholesale mobile network provider (or providers)
- Large amounts of public-sector spectrum (e.g. spectrum currently reserved for the Ministry of Defence, such as the lower 2.3GHz band) being made available on a shared access basis
- Particular bands becoming subject to demand from a range of user types (e.g. MNOs, private and local operators and short-range applications), requiring consideration of the extent to which licensed, lightly licensed and unlicensed spectrum can achieve the greatest balance.

For the avoidance of doubt, we are not advocating for any of these particular developments, but highlighting them as potential future scenarios which could be investigated in relation to the market mechanisms.

Further work could also consider if/how emerging and novel market mechanisms (such as ‘depreciating licences’ and ‘foothold auctions’) might be used in the context of these future developments.

2 Introduction

This is the final report from a study conducted by Analysys Mason, together with Professor Martin Cave,[12] for techUK, on behalf of the Spectrum Policy Forum (SPF). The study concerns the use of market-based approaches (or 'market mechanisms') as applied to licensed mobile spectrum bands in the UK.

Against a backdrop of continued rapid evolution of wireless services, networks and industry players, and possible further, potentially disruptive, changes in the mobile sector over the remainder of this decade, this study provides an independent review of the effectiveness of market-based spectrum management approaches for public licensed mobile spectrum. In the UK, the majority of spectrum used for public mobile services is licensed to MNOs. The purpose of the study has been to undertake an independent review of the three mechanisms that collectively make up the 'market mechanisms' as currently applied to national mobile spectrum – namely auctions, trading and pricing.[13]

2.1 Background

Since market mechanisms (namely auctions, pricing and trading) were introduced into the spectrum management framework around 20 years ago, these approaches have progressively been applied to all of the spectrum used for public mobile services. In the UK, the majority of spectrum used for public mobile services is licensed to national MNOs for their public mobile networks.[14]

In recent years, the introduction of new technologies, growing demand for mobile broadband services by consumers, and demand for mobile solutions from enterprise and business users have been key themes in the mobile market. However, the biggest recent development (which is still evolving) has perhaps been the changing shape of the industry, with new types of players (e.g. internet, cloud, private and local operators) looking to deploy mobile services.

The changing shape of the industry creates significant issues beyond those arising from spectrum management. However, in relation to spectrum management, which is the focus of this study, a key issue is that some new types of players will exhibit spectrum demand that is different from that of national MNOs; for example, concentrated into local areas, or for coverage in specific environments. There is also demand for the latest generation of mobile technology – fifth generation (5G) – to be deployed in private settings (for example, within factories, ports or airports) for bespoke industrial uses. This type of 5G deployment can be provided in various ways – either using spectrum licensed

12 Professor Cave assisted the authors in reconstructing the historical background, formulating future options and reviewing the draft report.

13 The pricing mechanism is based on an approach known as administrative incentive pricing (AIP).

14 It is noted that MNOs use some frequency bands for fixed-link backhaul within their mobile networks. Fixed-link spectrum has been assigned using various approaches in the UK, including co-ordinated link-by-link assignments from Ofcom and block licences. Some of the block licences (e.g. 40GHz) have been auctioned, with an initial licence term of 15 years. Bands that have not been auctioned and are available via Ofcom co-ordinated licences are subject to annual licence fees (ALFs).

to a national MNO (on a private or public network), or using spectrum that Ofcom has made directly available for this purpose. Many of these private networks will be on-campus, or deployed in specific locations only, hence requiring access to spectrum in only local areas.

A key motivation for this study is the extent to which changing demands in the mobile market bring into question the underlying philosophies of market mechanisms, and whether the design of the individual market mechanism approaches as applied to the current national mobile spectrum in the UK remains relevant and consistent with the objective of meeting emerging demand for spectrum.

2.2 Scope of the study

Nine scope items were defined in UK SPF's terms of reference. These scope items, along with the section(s) of the report in which they are covered, are shown in Figure 2.1 below.

Figure 2.1: Terms of reference [Source: techUK, 2022]

#	Terms of reference	Relevant section(s) of report
1	What has changed in the market circumstances over the past 20 years that challenge the underlying assumptions of Cave and how might this and the new challenges ahead change the approach today?	Covered throughout Section 3 and Section 4, and in Sections 5.1.1 and 5.3.1
2	Do the market mechanisms deliver what it is claimed they deliver? a) Do AIP[15]-based ALFs deliver on better economic spectrum efficiency? b) Do AIP-based ALFs deliver on better technical spectrum efficiency? c) Do spectrum auctions deliver the most efficient use of the spectrum?	Section 4.3, Section 5.2 and Section 5.3
3	What is the opportunity cost of the AIP-based ALFs in terms of benefit loss to consumers, wider economy and society (with illustrative examples)?	Section 3 and Section 5.4
4	What is the impact of Ofcom's competition policy and net neutrality regulation on the effectiveness of the market mechanisms?	Section 3.2 and Section 5.1
5	Can the market mechanisms distort competition between entities subject to the market mechanisms and those that are not?	Sections 4.2 to 4.3 and Section 5.4
6	Do the market mechanisms have any other significant negative unintended consequences?	Covered in Section 3.2 and throughout Section 5
7	Do the market mechanisms deliver the right spectrum when it is needed?	Covered throughout Section 5
8	Do the market mechanisms help or hinder innovation?	Section 4.3 and throughout Section 5
9	Are there any alternative spectrum regulatory models used in other countries that provide a useful comparative benchmark in respect of outcomes to the UK's use of the market mechanisms?	Throughout Section 5

15 Administered incentive pricing, which refers to pricing spectrum on the basis of opportunity cost across its alternative uses, as opposed to cost-based pricing, which recovers the cost of administering the licence.

This study concerns the application of market mechanisms for promoting efficient use of spectrum[16] and positive outcomes for users of mobile services.[17] Whether by design or not, some of the market mechanisms may also have a wider impact (e.g. generating an income for government from a scarce national asset – i.e. radio spectrum – which can in principle be used to generate wider social benefits[18]). As such, any changes to the market mechanisms may have an impact on more than just spectrum efficiency. Such considerations are beyond the scope of this study, although some stakeholders (e.g. HM Treasury) may wish to consider the incidental impacts of any changes to the market mechanisms, including those which form the basis for our recommendations.[19]

2.3 Approach to the study

The analysis presented in this report is based on a combination of desk research and a small number of targeted one-to-one discussions with selected stakeholders in the UK mobile market, together with consideration of international case studies (which are presented in this report). It was not intended that the analysis would draw on significant stakeholder consultation, but rather that it should represent an independent viewpoint. We acknowledge that there will be stakeholders in the UK market that have a different viewpoint from those expressed in this report.

The draft findings of this report have also undergone independent peer review by a group of experts appointed by UK Spectrum Policy Forum. The peer review team unanimously and fully endorsed Analysys Mason's summary table of conclusions. Details of the peer review team, and further information about the peer review findings are provided in Annex D. Analysys Mason would like to thank members of the peer review team for their inputs.

Following this process, further comments were gathered during an SPF Cluster 2 meeting with key stakeholders (verbally during the meeting and subsequently in writing). Analysys Mason also thanks stakeholders for these comments, which have been reviewed and considered by the Analysys Mason team in producing this final report.

2.4 Structure of this document

The remainder of this document is laid out as follows:

- Section 3 describes the evolution of the public mobile market since the time of publication of the Cave report

16 'Efficient use of spectrum' in this context refers to economic and technical efficiency as well as spectrum utilisation.

17 By 'users of mobile services' we mean both individual consumers and businesses making use of mobile services. By 'positive outcomes' we refer to the quality and price of the available mobile services.

18 For example, although not adopted as part of Ofcom's statutory duties under the 2003 Communications Act, the Cave report also proposed deriving full economic value from radio spectrum as a key governmental objective.

19 For example, if ALFs are removed from the currently assigned mobile bands, the government might consider whether some other form of one-off payment or taxation arising from use of a scarce national asset is appropriate. In relation to such considerations, we note that non-discrimination across all commercial users of the same scarce national asset (for example, DTT multiplex providers, private 5G network providers and LEO satellite operators) is likely to be an important principle.

- Section 4 discusses the future direction of the mobile market
- Section 5 provides our assessment of the effectiveness of existing market mechanisms
- Section 6 provides our recommendations on adapting market mechanisms for the future.

The report includes a number of annexes containing supplementary material:

- Annex A provides the master list of arguments against market mechanisms provided by techUK
- Annex B presents further information on the historical context of mobile technology evolution
- Annex C sets out key definitions and provides a list of acronyms
- Annex D provides details of the independent peer review team and its findings.

3 Market changes since the Cave report

The market mechanisms as applied to nationally licensed mobile bands in the UK today largely evolved based upon the findings of the Cave report, published in March 2002, although the use of both AIP[20] and auctions pre-dates the Cave report.

The AIP-based pricing concept was under development in the UK before 2000 as the basis of pricing for spectrum used by various sectors of use, including mobile, as an incentive to increase efficiency. In the case of nationally licensed mobile spectrum, which is the focus of this study, only one auction had been conducted prior to the Cave report (namely the 2000 auction of 2100MHz licences for third-generation mobile (3G)).

The decade following the Cave report, up to 2012 saw tremendous changes take place in the mobile market, with the number of mobile voice subscribers increasing enormously, and the introduction of 'mobile broadband', or mobile data, services initially through 3G, and then, from 2012 onwards, with 4G. In the decade from 2010 to 2020, the focus of the mobile market shifted from mobile voice subscriber growth to mobile data usage growth. During this period, mobile broadband became an indispensable service for most citizens, and it is now an essential part of the modern economy and of social life.[21] Since 2020, 5G services have been ramping up in the UK market and some aspects of what 5G can offer (especially non-consumer use cases) are still evolving. The further evolution of 5G networks and services over the remainder of this decade, accompanied by other trends in the telecoms market more broadly, may result in significant, potentially disruptive, changes occurring in the mobile market.

The remainder of this section is structured as follows:

- In Section 3.1 we provide a summary of the Cave report's objectives and recommendations
- In Section 3.2 we discuss changes that have taken place in the UK mobile market since the Cave report was published, and also discuss expected future developments.

20 Here we refer to AIP in its broadest sense, i.e. the setting of ALFs above administrative cost to reflect certain spectrum management objectives. As discussed in Section 5.3.1, AIP has been applied to certain nationally licensed mobile spectrum bands in the UK since the late 1990s, but was not set to reflect 'full market value' until 2015 (and, due to legal challenge, final values were not set until 2018).

21 As an essential service, it is unclear how acceptable (e.g. politically) it would be to reassign spectrum to another service, even if that service was more efficient, if this would compromise the delivery of mobile broadband services.

3.1 Cave report objectives and recommendations

Professor Cave published his *Review of Radio Spectrum Management* in March 2002 as an independent study commissioned by the Department of Trade and Industry and HM Treasury.[22,23]

The primary purpose of the Cave report was to "*look forward to the principles which should guide the Government and Ofcom in managing access to the radio spectrum in the years ahead, in order to derive most value from this national asset for the UK as a whole*".[24]

The Cave report summarises its recommendations as follows: "*the use of markets (spectrum trading and auctions) to allocate spectrum in commercial use, and the continued reservation of spectrum for public service use, coupled with an administrative charge designed to ensure economy and efficiency of its use*".[25]

Particular recommendations regarding use of market mechanisms for spectrum management included the following:

- "*Spectrum trading should be implemented in the UK as soon as possible. The trading regime should be designed to minimise the transactions costs of trading*" [paragraph 7.2]
- "*Auctions should become the default means of assigning spectrum licences between competing users, to achieve an efficient market-driven outcome*" [paragraph 7.7]
- "*Spectrum pricing should be applied at more realistic levels and more comprehensively across spectrum uses. Where spectrum pricing has already been implemented, and where there is evidence of continuing shortage of spectrum, then incentive prices should be set at the full opportunity cost level … [and should be] subject to regular review*" [paragraph 7.9]

The Cave report also made recommendations related to how government might price spectrum in relation to objectives other than promoting efficiency via market mechanisms:

- "*The Government should assess the case for levying a duty on net gains from spectrum trades and/or continuing with spectrum pricing for tradable licences, against its objectives of encouraging efficient use of spectrum and achieving full economic value for consumers, industry and the taxpayer*" [paragraph 7.6].

It should be emphasised that the present study is only concerned with the use of market mechanisms in the mobile market, and therefore has a more specific focus than the Cave report's broader review

22 http://web1.see.asso.fr/ICTSR1Newsletter/No004/RS%20Management%20-%202_title-42.pdf

23 The Cave report was followed by an 'independent audit of spectrum holdings', also overseen by Professor Cave, focusing on spectrum used by the public sector, and the scope for increased commercial access to this spectrum to meet growing demand for new wireless services. This is discussed in Ofcom's Spectrum framework review for the public sector, see: https://www.ofcom.org.uk/__data/assets/pdf_file/0018/29106/sfrps.pdf

24 Paragraph 9, Executive Summary.

25 Page iv (Foreword).

of radio spectrum management. For this reason, we only engage with the Cave report's points as they relate to the mobile market and to market mechanisms.[26]

In October 2002, the government published its response to the review, endorsing the Cave report's recommendations for increasing reliance upon the market, rather than administrative systems, for the management of spectrum. Subsequently, the Select Committee on Trade and Industry published its Third special report in December 2002, which outlined future changes to radio spectrum management.[27]

3.2 Evolution of the public mobile market

In this section we discuss key changes that have taken place in the UK mobile market since the Cave report was published, and how these may motivate considerations related to adaptation of the market mechanisms. Specifically, this section discusses:

- The evolution of mobile technology through successive generations (namely 3G, 4G and 5G, and beyond), including discussion of the global convergence of mobile technologies (defined by the Third Generation Partnership Project (3GPP)), the potential new business models and new players that may be enabled by 5G and future wireless technologies (Section 3.2.1)
- The transition of mobile networks from being voice-centric to being data-centric, and the huge growth in mobile data usage (Section 3.2.2)
- The release of further mobile spectrum into the market on a nationwide basis (Section 3.2.3)
- The recent introduction of shared and local access licences (Section 3.2.4)
- The evolution of mobile technologies and a shift to use of higher frequencies (Section 3.2.5)
- The evolution of MNOs' investment requirements, retail prices and resulting returns (Section 3.2.6)
- Mobile coverage, and the coverage obligations which have been imposed on the UK MNOs (Section 3.2.7)
- The introduction of net neutrality legislation alongside the rise of over-the-top service providers driving growth in mobile data usage (Section 3.2.8).

26 Paragraph 8.1 is the only specific recommendation in the Cave report for public telecoms spectrum: *"Auctions should be used to assign spectrum available for public telecoms use. Where spectrum pricing is currently used, prices should be raised to the full opportunity cost levels. Once spectrum trading is introduced, public telecoms operators should be able to trade spectrum subject to international constraints"*.

27 https://publications.parliament.uk/pa/cm200203/cmselect/cmtrdind/128/12802.htm

3.2.1 Evolution of mobile technologies, networks and architectures

Mobile technology evolution

Since the Cave report was published, 3G, 4G and most recently 5G networks have been launched by the UK MNOs.[28] These successive generations of mobile technology were designed with various goals in mind, one of which is to increase technical spectrum efficiency.

Increases in technical spectrum efficiency are motivated by both demand- and supply-side factors. A key factor on the demand side is increased use of mobile broadband services, leading to a desire among MNOs to be able to carry more data traffic within existing bandwidths.

As shown in Figure 3.1 below, on the demand side of the market, the dominant mobile technology today is 4G (although this is being progressively complemented by 5G, as consumers increasingly adopt 5G-enabled devices and 5G technology is rolled out to a greater portion of mobile sites). Usage of second- and third-generation mobile (2G and 3G) connections in the UK has dropped significantly. A key reason for this drop in 2G/3G use is the growth of mobile data applications, and a decline in mobile voice services (as discussed in Section 3.2.2).

On the supply side of the market, the standardisation of mobile technologies that the UK MNOs deploy is now concentrated within the industry standardisation body called the Third Generation Partnership Project (3GPP). The 3GPP group is responsible for the development of specifications for the 4G, and 5G, technologies that are deployed by the UK MNOs (and by many MNOs worldwide). The convergence of mobile technology standardisation within 3GPP to effectively one common global set of standards means that there are less marked differences in technical spectrum efficiency in a given network environment among MNOs than might have been the case if different operators had chosen to deploy different technologies with fundamentally different radio interfaces.

Although MNOs in the UK have all used the same technologies for each mobile generation, the way that networks are deployed varies, with each UK MNO having different network footprints, site grids and capacity levels, which may have an impact on the economic spectrum efficiency of use by each operator. This can be seen, for example, in the substantially different amounts that UK MNOs bid for identical packages in the supplementary round of the 800MHz and 2.6GHz auction in 2013.[29] In Analysys Mason's extensive experience of carrying out spectrum valuations for MNOs bidding in auctions, there is often a very significant disparity in valuations for equivalent packages for different operators in the same market.

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28 Annex B presents further information on the historical context of mobile technology evolution.

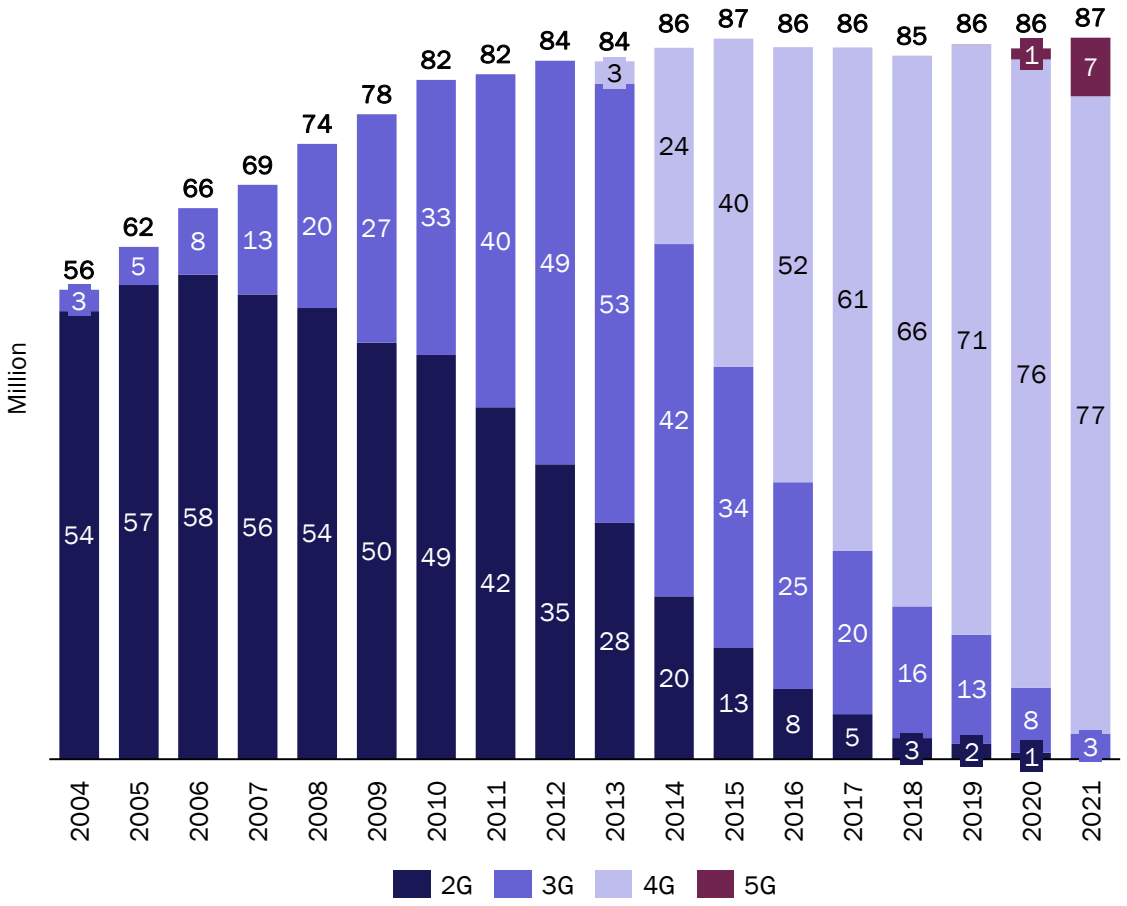
29 For example:

- for the single 2×10MHz lot in the 800MHz band with coverage obligations attached, EE bid GBP250 million, Three bid GBP591 million and Telefonica bid GBP1 219 million;
- for a package of two 2×5MHz lots in the 800MHz band and two 2×5MHz lots in the 2.6GHz FDD band, EE bid GBP865 million, Telefonica bid GBP1 347 million and Vodafone bid GBP1 744 million.

See https://webarchive.nationalarchives.gov.uk/ukgwa/20220104120035mp_/http://static.ofcom.org.uk/static/spectrum/800_2.6_auction_bid_data_files.zip

The 3GPP specifications cater for variations in spectrum band deployment, such as carrier aggregation, flexible carrier spacing, frequency division duplex (FDD) and time division duplex (TDD) variants. This means that the performance and services offered by the four MNO networks in the UK varies depending on an individual MNO's spectrum holdings, and site grids, and also dictated by individual operator customer needs.

Figure 3.1: Total active mobile connections in the UK (excluding IoT)[30] [Source: Analysys Mason, 2022]



3GPP's technologies are defined in two modes of operation – FDD, which uses paired spectrum, and TDD, which uses unpaired spectrum. Both FDD and TDD versions of the latest 3GPP standards (i.e. 4G onwards) are optimised for data communications (i.e. based on the Internet Protocol (IP)).

For voice communications, 4G networks initially built upon legacy 2G/3G deployments to offer voice (i.e. via circuit-switched fallback (CSFB)) before the packet-based voice solution, voice over long-term evolution (VoLTE), was introduced. By the time 4G networks were introduced into the UK market, new mobile devices were emerging globally (e.g. Apple's iPhone). To enable a smooth migration of existing mobile customer bases, and due to the reliance on 2G/3G for voice, 4G devices also supported 2G/3G.

30 Internet of Things.

By design, 5G was launched initially in the UK as a new radio technology built onto existing macro sites, linked to the 4G networks using existing core network architectures. As with 4G, the standards for 5G are developed by 3GPP. The initial release of 3GPP's 5G specifications ('Release 15') essentially enabled operators to offer 5G-based mobile broadband services, by adding 5G radio to existing sites, linked via the 4G core networks. Subsequent releases of the 3GPP specifications are adding enhancements to Release 15, particularly in relation to the latency and density of devices, enabling additional services, improved performance and more fundamental architectural changes using cloud, and edge, technologies.

One of the main initial drivers for 5G networks in the UK has been to carry increasing volumes of data traffic via new spectrum. This is driven by the growing volumes of mobile broadband data (see Section 3.2.2) together with the flattening average revenue per user (ARPU) that has been a feature of the UK market throughout the 4G era (see Section 3.2.6). The use of 3.4–3.8GHz spectrum – where wider channels can be provisioned – along with massive MIMO lowers the 'cost per bit' compared to earlier mobile systems.

Initial 5G networks in the UK have used spectrum in the 3.4–3.8GHz band in conjunction with 4G use in other existing mobile bands (e.g. 1800MHz and 2100MHz), and 700MHz. 5G technology is also standardised to use higher bands (such as 26GHz). Currently, 26GHz use in the UK is permitted in indoor locations only, but Ofcom is consulting on opening further bandwidth for 5G use, in the 26GHz and 40GHz bands.

The various frequency layers used within a 5G network (i.e. 700MHz and other sub-1GHz bands, combined with existing mobile bands in, for example, 1800MHz and 2100MHz, and new spectrum in the 3.4–3.8GHz band) gives rise to varying levels of network coverage, performance and capacity. Consumers using a mobile handset will not necessarily be aware of the frequency layer that the network is using, since a device will simply say "5G". However, in practice, the greatest improvements in technical spectrum efficiency and capacity from 5G are limited to locations where the 3.4–3.8GHz band is deployed.

However, use of the 3.4–3.8GHz band on its own will not offer a good level of indoor coverage, if deployed on outdoor macro cells (which has been the predominant deployment model of UK MNOs to date). MNOs generally favour the use of lower frequency bands (e.g. below 1GHz) to provide in-building penetration via outdoor macro cells (given that the propagation properties of lower frequencies are more favourable for penetrating buildings). The bandwidth available in the spectrum below 1GHz is more limited than in the 3.4–3.8GHz band, and massive MIMO technologies are not designed to use these lower bands. This means that the sub-1GHz bands can become congested in locations with high traffic load, which degrades the in-building coverage. While the geographical reach of lower frequencies is greater, the capacity is limited, and so a low-band 5G service might be hard to differentiate in capacity/speed terms from a 4G service. As a result there is a risk of mobile network quality disparities across different parts of the UK, depending on the spectrum deployed.

Hence, achieving better indoor coverage might also require a combination of solutions, alternative technologies and architectures. These are further described in the next section.

Architecture evolution and deployment models

In accordance with the 3GPP specifications, MNOs had various architectural options for 5G deployment, although at the time that 5G launches occurred in the UK (i.e. in 2019/20) the most established technological option (and the available 5G devices) built upon 4G networks. There is, however, a future upgrade path to migrate to a fully 5G-controlled architecture. This architecture, called '5G standalone', is the next significant step in 5G evolution anticipated in the UK market. This evolution to 5G standalone is expected to be accompanied by various other technological changes such as use of edge cloud technologies, virtual radio access network (RAN), 5G millimetre-wave (mmWave), and greater use of small cells.

Alongside these architectural changes, there will also be changes in the way that radio networks are deployed. In particular, an objective of Open RAN is to open the interfaces within mobile RANs through software-based developments. In turn this is likely to enable new business and deployment models (including neutral host provision, and shared RAN), and might also allow for more rapid deployment. The Department for Culture, Media and Sport (DCMS) Future Radio Access Network Competition (FRANC) has awarded grant funding to a variety of Open RAN projects, with the aim of accelerating these architectural developments in the UK.[31] Self-provision of private 5G networks is already emerging and could become the preference for enterprises and industrial users of 5G.

Open RAN technologies (and standalone 5G architectures) will not in themselves improve the coverage of mobile networks, since coverage is primarily dependent on the location, and type, of base stations deployed in the networks (as well as the frequency bands used). To date, mobile networks in the UK have primarily used outdoor 'macro' sites to provide mobile coverage. Macro sites (or macro cells) are base stations located on towers, or on rooftops of buildings, which operate at high power and have a large coverage area. In some locations 'small cells' have also emerged, which typically refer to smaller base stations that might be located at street level. These small cells can be used to provide targeted outdoor coverage/capacity but their deployment may involve complexities (such as gaining access to the relevant street-level infrastructure, and providing power and backhaul links). Alternatively, small cells can be deployed in indoor settings, either as part of a public mobile network, or as a private network solution.

As with previous mobile generations, there is significant debate in the UK on the topic of improving 4G, and 5G, mobile coverage in both outdoor and indoor settings, as well as how future wireless connectivity capacity needs will be met. Ofcom's 2021 Connected Nations report states that, in the UK, all four MNOs provide over 99% of premises with outdoor 4G coverage (with around 98% of premises having coverage from all four MNOs) and that 92% of the UK landmass has 4G coverage from at least one MNO. Ofcom also estimates that MNOs provide indoor 4G coverage to between 90% and 95% of premises, although the portion of premises receiving indoor coverage reduces in rural areas.[32] Providing the depth of coverage needed indoors is a complex problem for which there are various solutions (e.g. indoor small cells, Wi-Fi as an alternative to a mobile network, and other

31 See https://www.gov.uk/guidance/future-ran-diversifying-the-5g-supply-chain-competition-winners

32 See https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf

specific in-building solutions). The problems associated with improving rural coverage in locations which are both hard to reach and sparsely populated (hence with limited revenue upside for operators that invest in these areas) are well documented.[33]

Private Wi-Fi is a primary solution used for indoor coverage, and is widely deployed in residential and commercial settings in the UK. The latest generations of Wi-Fi solution (e.g. Wi-Fi 6) offer superior quality of service to earlier generations, aided by the use of new spectrum in the 6GHz band. However, whilst some regulators have already made the entire 6GHz band available for Wi-Fi use, future use of the upper part of the 6GHz band (from 6425–7125MHz) is the subject of ongoing policy debate in the UK, and the rest of Europe, and is the topic of an agenda item to be considered at the World Radiocommunication Conference in 2023 (WRC-23). This is further discussed in Section 4.2.

We note that future in-building deployment of 5G could increasingly take place through Wi-Fi, or through deployment of indoor small cells, deployed either by MNOs or by third parties.

Addressing mobile 'notspots' and improving the consistency of coverage from mobile networks (both outdoors and indoors) is also incentivising new types of players in the UK market. One such example is Telet, which aims to cover rural notspots and deliver public and private 5G networks for enterprises.

As well as localised players offering consumer services, new types of private 5G networks are emerging in the UK market. These private 5G networks might be suitable for use by enterprises, industrial firms, event providers and others. Whilst the MNOs themselves also offer enterprise services, and are providers of private 5G networks, other 5G private network providers include equipment vendors, systems integrators and internet companies, among others. For example, a recent announcement on private 5G networks has come from Amazon Web Services (AWS), which is offering a managed service called AWS Private 5G. This offers rapid deployment and a packaged solution for outdoor or indoor use in settings such as enterprise locations, factories, campuses, warehouses and event venues.

The AWS solution is designed to operate in the 'CBRS' spectrum band in the USA (which is in the 3.55–3.7GHz band). CBRS refers to the Federal Communications Commission (FCC) Citizens Broadband Radio Service model, a tiered spectrum authorisation framework which is designed to accommodate commercial use of the 3.5GHz band alongside incumbent federal/government, and fixed satellite, use.[34]

In the CBRS model, there are three different tiers of use (incumbent, priority and general access). Incumbent federal/satellite use has pre-emption over the priority and general access uses. The priority tier consists of 70MHz of spectrum per region, packaged into priority access licences (PALs) and auctioned for mobile use subject to ten-year renewable licences. PAL licensees must comply with power limits to prevent interference to the incumbent tier.

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33 For example, https://www.ofcom.org.uk/__data/assets/pdf_file/0015/130812/Improving-mobile-coverage.pdf, and https://www.gov.uk/government/news/shared-rural-network

34 See https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

AWS's private 5G solution uses spectrum in the general access tier, which is spectrum that is open to general use, subject to low-power and other shared access restrictions (e.g. on locations where systems can be deployed) to avoid interference to the priority and incumbent tiers. The shared access use in the CBRS model is managed via database-technology spectrum access systems (SASs).

The unique feature of this model compared to other forms of spectrum shared access is its mix of tiers of service. The general access layer is similar to licence-exempt spectrum, or 'lightly licensed' shared access 5G in the 3.8–4.2GHz band in the UK, in that it offers flexible use to a wide range of potential users.[35] However, the UK approach has been to set aside spectrum for licence-exempt, or lightly licensed shared access, use, in a different band from that used by mobile operators for their public mobile networks By contrast, in the USA's CBRS model, mobile operators have access to licensed spectrum (via PALs) in the same (3.45–3.55GHz) range.

An Ofcom 2022 discussion paper on the future approach to mobile markets set out Ofcom's expectation that development of 5G will lead to increased competition to deploy and operate private networks in the UK, with a wide range of players involved in their deployment (e.g. the MNOs themselves, equipment vendors, managed service providers and systems integrators, and hyperscalers).[36] Ofcom also refers to there potentially being greater opportunities for mobile networks to share spectrum with other users in future, such as through more localised access and low-powered (e.g. small-cell) use. The evolution of mobile architectures to use cloud, and edge, technologies creates opportunities for partnerships between hyperscalers and MNOs to use the hyperscaler cloud and edge estates within mobile networks.

Key implications for market mechanisms

The prospect for development of new business models, new deployment models (such as lower-powered cells for tailored coverage in specific locations) and new types of players in the mobile market raises questions about the most suitable licensing approach for mobile spectrum in the future. It is therefore relevant to consider the suitability of the current market mechanisms (which are applied to national mobile spectrum) for any future mobile spectrum (which might be assigned sub-nationally, and might be shared among mobile and other uses).

A key issue is that in the remainder of this decade there is expected to be increasing demand for access to spectrum to provide additional capacity in localised areas. This capacity might be needed to address specific types of demand, such as in industrial settings (for example, to meet the demand for bespoke, private 5G networks) or indoor settings (e.g. within homes, offices and public buildings, where data consumption levels might be very high). The coverage provided in these localised areas might be delivered through a combination of medium- and low-powered cells (including small cells), alongside the higher-powered base stations that have historically been deployed in mobile networks.

35 Note that the general access tier is often referred to as licence-exempt, but users are 'licensed-by-rule' (i.e. they must meet the FCC's technical, financial, character and citizenship qualifications to be eligible). See https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

36 https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf

More broadly, small cells might also be deployed by MNOs in certain situations to densify infrastructure where additional capacity is needed.

The use of lower powers in small-cell deployments may have a key benefit in that it may create an additional opportunity for sharing between mobile use and existing services in future, or facilitate sharing between different types of mobile use (e.g. public mobile, and private mobile, deployments).

Looking ahead, fundamental changes in the way mobile technologies are designed (such as Open RAN) might give MNOs further options for innovative deployment, creating potential for greater diversity, new business models and less capital-intensive deployments, although such changes may take some years yet to implement. Furthermore, it is not yet clear whether Open RAN will have an impact on the structure of the UK mobile market, although it is possible that there will be greater incentive for MNOs to innovate in response to disruption from internet players and others through Open RAN deployment, network virtualisation and other related technology developments.

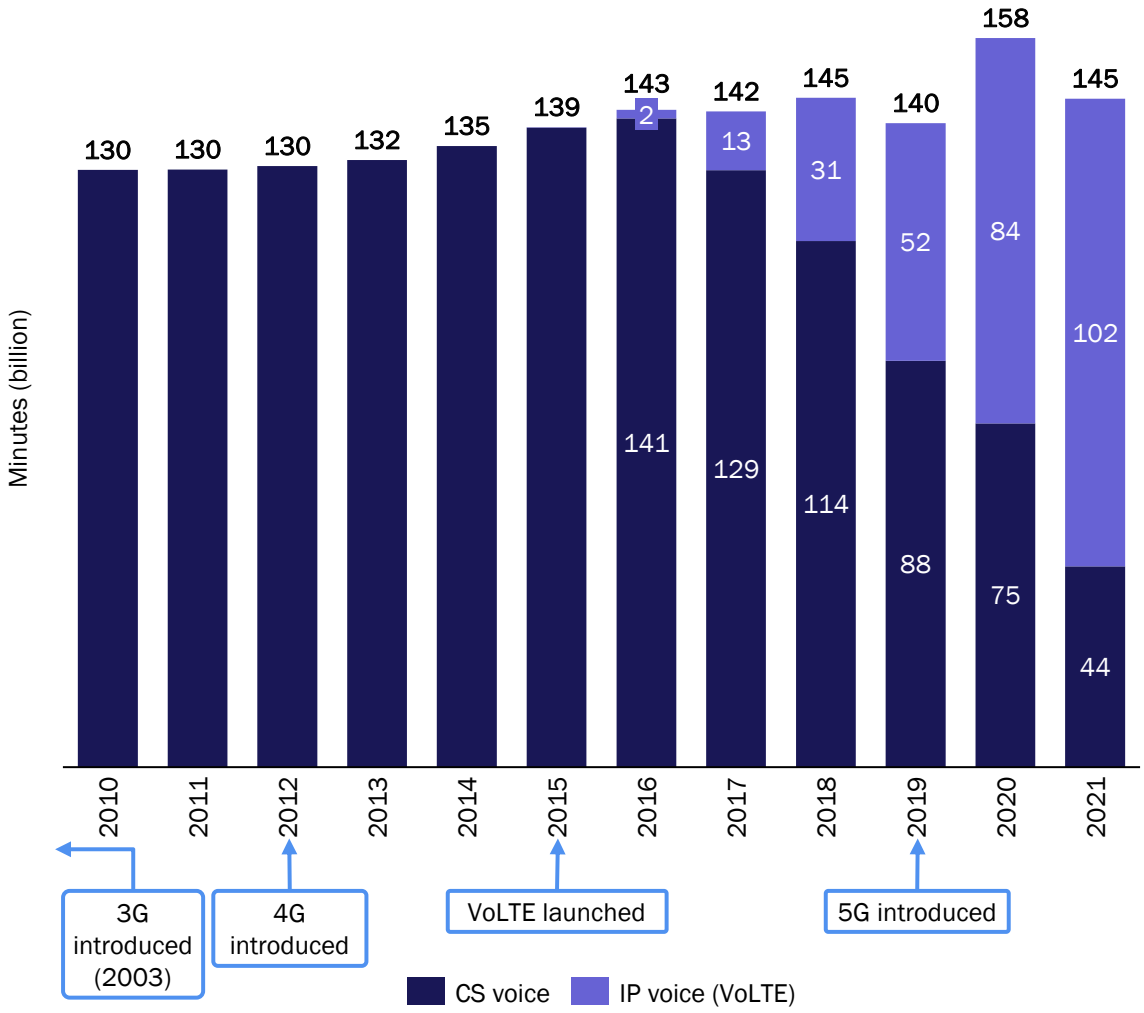
3.2.2 Growth of mobile data, and decline of mobile voice, and the associated implications for mobile networks

Relative decline of voice

Figure 3.2 below shows the evolution of mobile voice traffic volumes over the last decade. It can be seen that total voice traffic has been relatively flat, although volumes spiked in 2020 due to the Covid-19 pandemic. The mix of traffic is shifting rapidly from circuit switched (CS) to packet switched (PS) following the launch of VoLTE. VoLTE was first introduced in the UK by Three in 2015, with other operators following suit in 2016 and 2017.[37] Voice is now included in most mobile subscriptions at no incremental price, with retail propositions now focused on data services.

37 https://www.gsma.com/futurenetworks/wp-content/uploads/2018/12/VoLTE-Launches-Nov-2018.pdf

Figure 3.2: Historical evolution of mobile voice traffic in the UK[38] [Source: Analysys Mason, 2022]



Growth of data

While voice traffic has been fairly flat, Figure 3.3 and Figure 3.4 below show the strong growth in smartphone penetration and mobile data traffic in the UK over the last decade. Since the Cave report was written, mobile has transitioned from a voice-centric service (in which voice was the key revenue driver for MNOs) to a data-centric service, with smartphones (and other mobile broadband devices) now in near-ubiquitous use across the UK population.

38 The chart shows the number of operator-billed minutes (CS and VoLTE) originating on mobile networks in the UK. This includes traffic generated by customers of service providers using the networks (e.g. MVNOs). Wi-Fi calling carried over fixed networks is excluded. Values for 2021 are calculated using a forecast split of technologies applied to the 2021 total value for voice traffic.

Figure 3.3: Historical evolution of smartphone penetration in the UK[39] [Source: Analysys Mason, 2022]

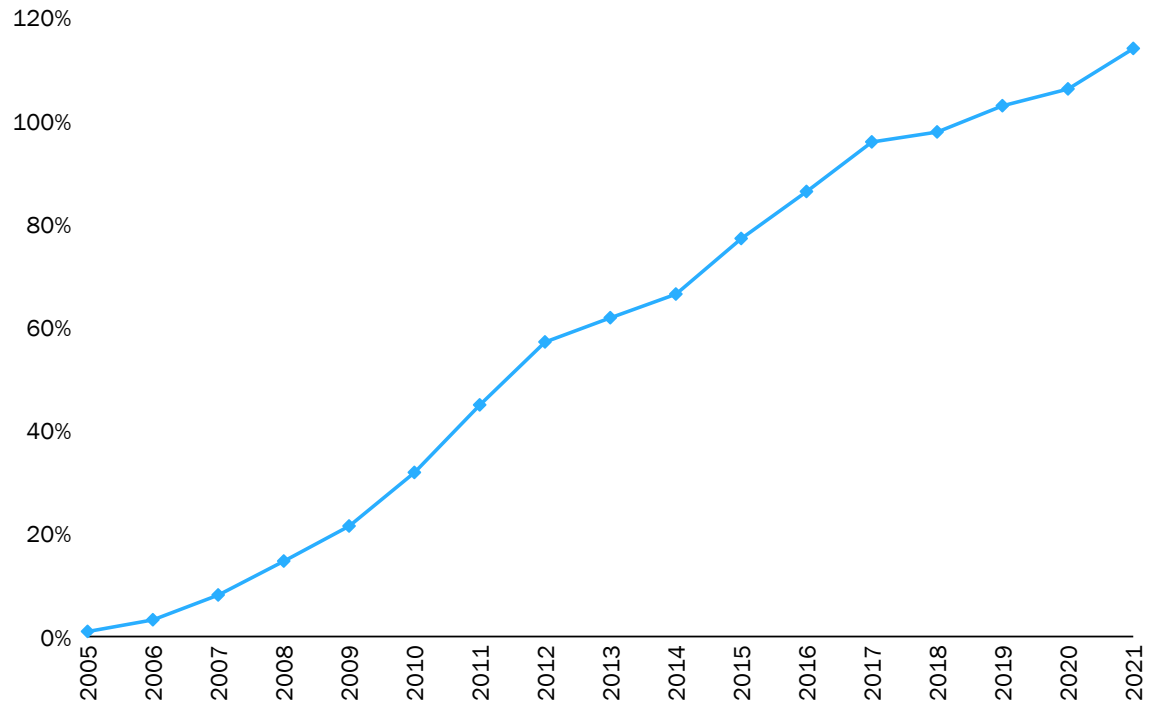
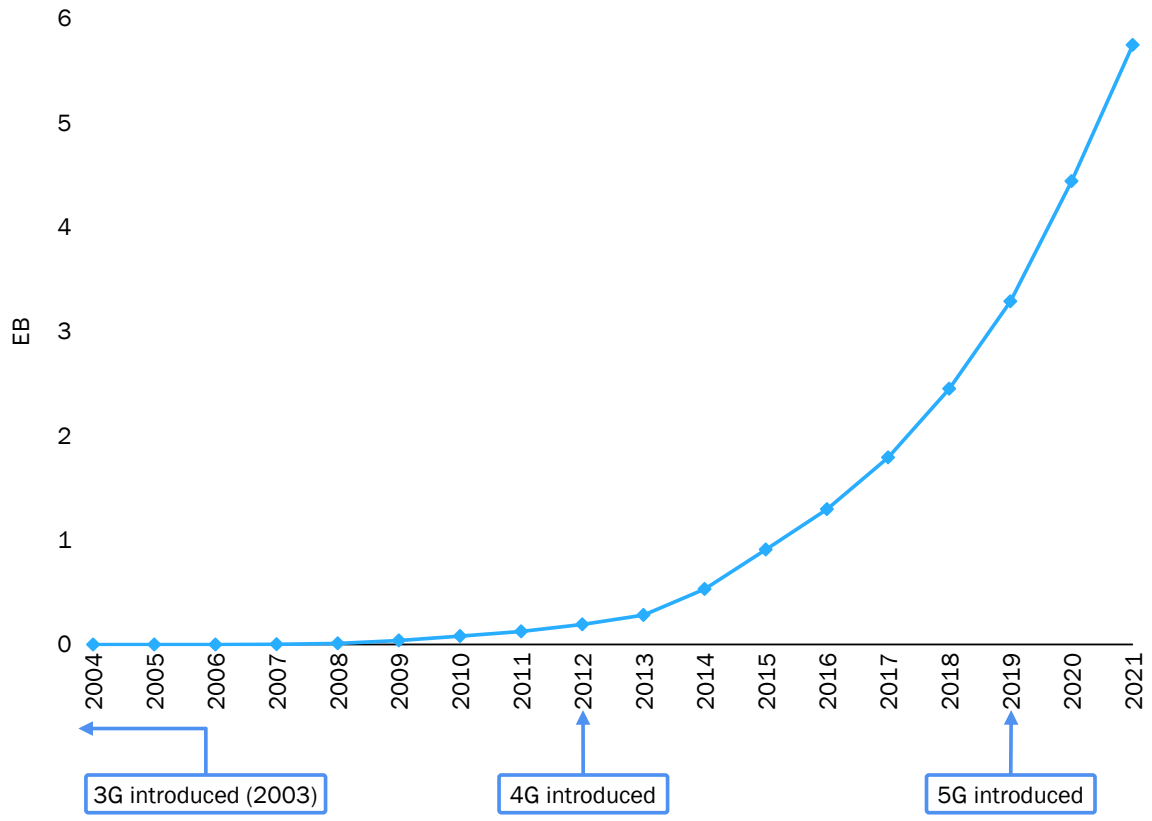


Figure 3.4: Historical evolution of cellular data traffic in the UK[40] [Source: Analysys Mason, 2022]



39 Active smartphones divided by population.

40 Total cellular data traffic (downstream and upstream) generated by all cellular devices (including fixed-wireless devices). Excludes Wi-Fi offload.

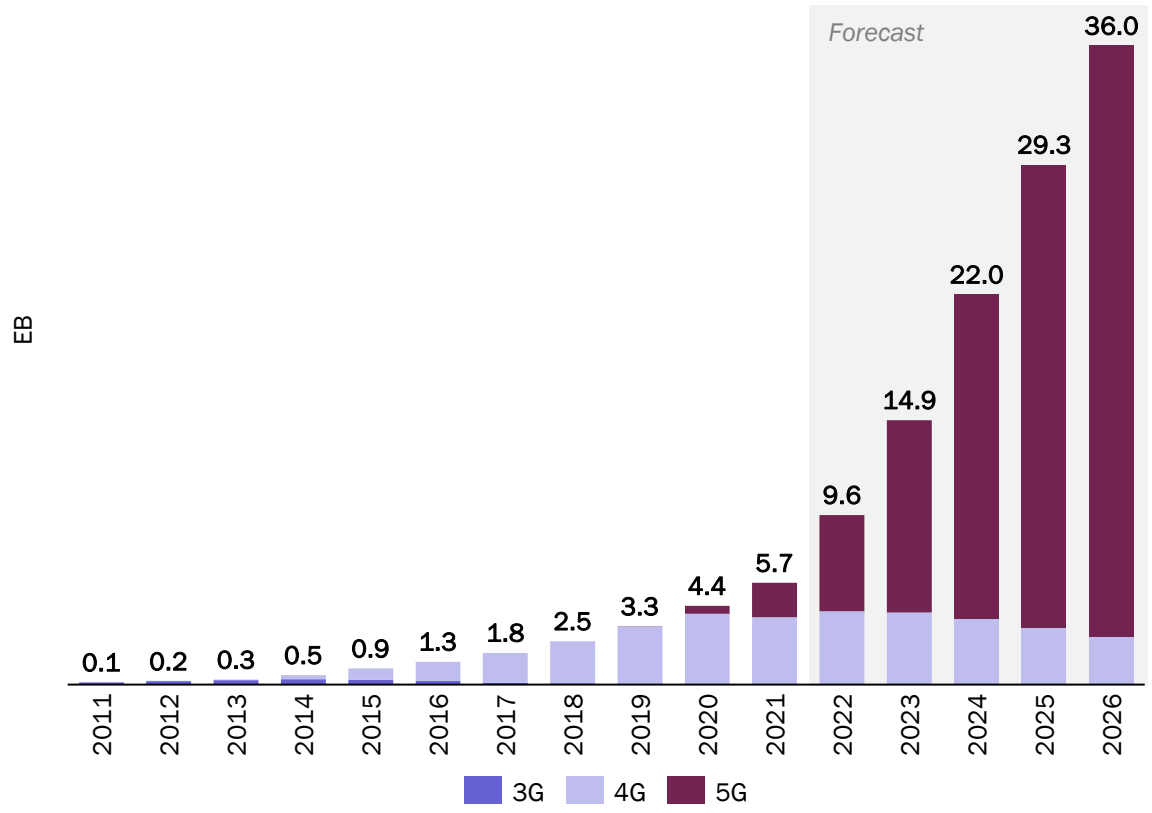
Further growth in data traffic is expected. In February 2022, Ofcom released a discussion paper on meeting the future demand for mobile data,[41] which outlined three potential scenarios for future growth of mobile data traffic up to 2035.

- **Low growth scenario**: 25% year-on-year increase to 2030, and 20% year-on-year increase from 2030 to 2035
- **Medium growth scenario**: 40% year-on-year increase to 2035 (i.e. a continuation of the growth experienced in recent years)
- **High growth scenario**: 55% year-on-year increase to 2030, and 60% year-on-year increase from 2030 to 2035.

Accommodating these traffic growth scenarios will require additional network capacity to be rolled out, to avoid widespread network congestion. However, the extent of future data traffic growth will be affected by the take-up of new applications and devices and the development of new technologies, as well as MNO decisions on investment, deployment and pricing. These decisions are subject to significant uncertainty.

Figure 3.5 and Figure 3.6 below show Analysys Mason's forecasts for cellular data traffic until 2026, split by technology.

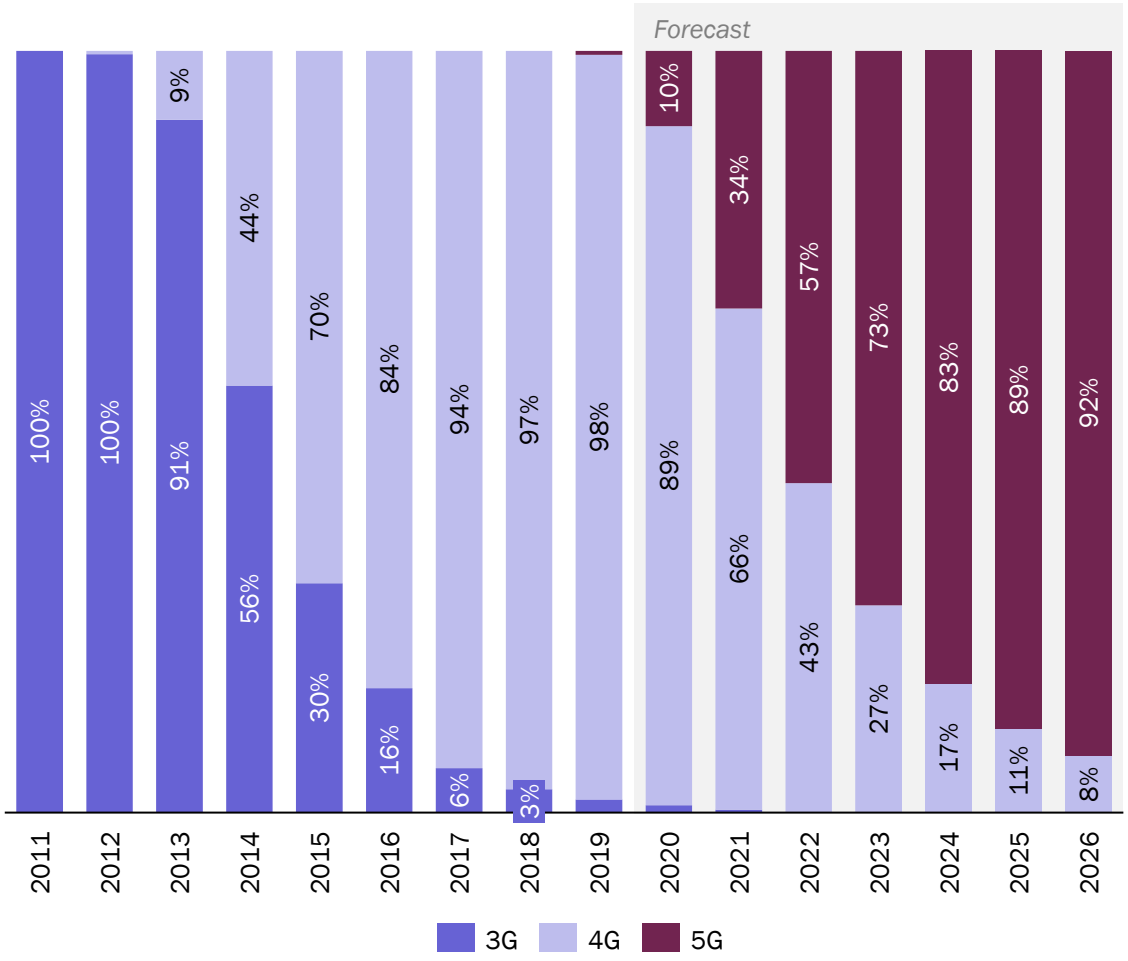
Figure 3.5: Forecast cellular data traffic by technology[42] [Source: Analysys Mason, 2022]



41 https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

42 Total cellular data traffic (downstream and upstream) generated by 3G/4G/5G cellular devices (including fixed-wireless devices). Excludes Wi-Fi offload. Values for 2020 and 2021 use actuals for total data traffic, but the 4G/5G split is calculated using a forecast split of technologies.

Figure 3.6: Forecast cellular data traffic by technology (% of total traffic)[43] [Source: Analysys Mason, 2022]



Key implications for market mechanisms

The significant rise in data traffic is driving various areas of future focus in the mobile market. These include:

- a shift from deriving revenue primarily from mobile voice usage to subscriptions with bundled services plus data usage
- further increases in peak data rates
- optimisation of IP and cloud-based network operation (and, especially with 5G, a move to cloud-based, virtualised architectures, edge clouds and private networks)
- a need for network densification (e.g. small cells) in the most heavily used network locations, and a need to address specific coverage environments (such as indoors)

43 Total cellular data traffic (downstream and upstream) generated by 3G/4G/5G cellular devices (including fixed-wireless devices). Represents the sum of business and residential mobile segments. Excludes Wi-Fi offload.

- flexibility to use more frequency bands, and technologies, within the same network/device. For example, along with Wi-Fi and Bluetooth, future mobile devices may support other short-range wireless technologies such as ultra-wideband (UWB) technology.[44]

As data traffic has grown and mobile networks have become ever more integral to the lives of consumers, businesses and the wider economy, it is now clear that MNOs are the highest-value users of the spectrum that is already available for public mobile use (something that was less certain at the time of the Cave report). This calls into question whether AIP is required to promote efficiency in the mobile bands.

The concentration of data traffic growth in localised environments (e.g. urban centres, and indoor locations) also calls into question whether any new mobile spectrum assigned in the UK will be needed on a nationwide basis, or whether demand will become increasingly concentrated in urban locations. Alongside this, there are also questions about how to ensure that rural areas receive adequate mobile connectivity. Spectrum access for local players is one way to incentivise better rural coverage (and this is already being progressed in the UK through the local licensing framework). Investment incentives for MNOs to improve mobile coverage are also relevant, as discussed in Section 3.2.7.

3.2.3 Assignment of spectrum for wide-area mobile use

The launch of 4G and subsequently 5G networks, and accommodation of huge growth in mobile data traffic over the last decade has been enabled through the introduction of new radio technologies in the RAN combined with new antenna technologies (e.g. massive MIMO), plus the release of significantly more spectrum for mobile than was assigned at the time of the Cave report. There is also greater use of network densification techniques (e.g. small cells) in 4G and 5G than in previous mobile generations, which can be deployed to increase network capacity.

The following subsections discuss the spectrum which has been made available for mobile use to date on a nationwide (or sub-national/wide-area) basis, as well as the future landscape for mobile spectrum assignment.

Current assignment of spectrum for nationwide mobile use

The first auction of mobile spectrum in the UK took place in 2000. Since then, auctions have become the standard approach for releasing spectrum into the market for nationwide use. Figure 3.7 below shows the spectrum bands in which nationwide licences are now available for public mobile use in the UK.

44 See, for example, https://support.apple.com/en-us/HT212274

Figure 3.7: Bands awarded directly for public mobile use in the UK as nationwide licences [Source: Ofcom,[45] 2022]

Initial expected technology	Bands	Assignment approach (date)	Licence duration	Permitted technology
2G (and pre-2G)	900MHz and 1800MHz[46]	Administrative assignment via a series of beauty contests[47] (pre-2000)	Indefinite (subject to ALFs), subject to a notice period of five years	In 2011, licences were varied to allow 3G use,[48] and again in 2013 to allow 4G use.[49] Ofcom has recently varied licences to allow 5G use[50]
3G	2100MHz	Auction (2000)	Initial 20-year duration (expiring end of 2021) In 2011, licences were varied to be indefinite (with ALFs due after the initial 20-year term)[51]	In 2013, licences were varied to allow 4G use.[52] Ofcom has recently varied licences to allow 5G use[50]
4G	800MHz and 2.6GHz	Auction (2013)	20-year auctioned term and then indefinite (with ALFs due after the initial 20-year term)	Technology neutral. Ofcom has recently varied 2.6GHz licences to facilitate 5G use[50]
4G/5G	2.3GHz and 3.4GHz	Auction (2018)	20-year auctioned term and then indefinite (with ALFs due after the initial 20-year term)	Technology neutral (in unpaired frequency blocks suitable for 4G/5G use)

45 https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive, https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/mobile-wireless-broadband/below-5ghz

46 In 1985, two licences were granted for analogue 1G services in the 900MHz band. In 1992, licences were varied to allow 2G technology to be deployed, and 2G 1800MHz licences were granted. In 1993/94, two further 1800MHz licences were granted. See Figure 1 of https://www.ofcom.org.uk/__data/assets/pdf_file/0026/237824/vodafone-telefonica-licence-variation.pdf

47 Three UK acquired spectrum in the 1800MHz band as a result of a spectrum divestment imposed by regulatory authorities in response to the merger between Orange and T-Mobile, to create EE.

48 https://www.ofcom.org.uk/__data/assets/pdf_file/0020/74702/statement.pdf

49 https://www.ofcom.org.uk/consultations-and-statements/category-2/variation-900-1800-2100

50 https://www.ofcom.org.uk/consultations-and-statements/category-2/vodafone-and-telefonica-request-to-update-technical-conditions-of-mobile-licences

51 https://www.ofcom.org.uk/consultations-and-statements/category-2/2100-mhz-third-generation-mobile

52 https://www.ofcom.org.uk/consultations-and-statements/category-2/variation-900-1800-2100

Initial expected technology	Bands	Assignment approach (date)	Licence duration	Permitted technology
5G	700MHz and 3.6GHz	Auction (2021)	20-year auctioned term and then indefinite (with ALFs due after the initial 20-year term)	Technology neutral (in paired (700MHz) and unpaired (700MHz and 3.6GHz) frequency blocks suitable for 5G use)

Other bands were originally assigned for non-mobile terrestrial wireless purposes (e.g. fixed-wireless access (FWA)) or other fixed uses) but have subsequently become available for mobile use, in line with spectrum harmonised for mobile use in Europe, and globally, expanding to cover more bands (including at higher frequencies).[53] These are shown in Figure 3.8 below.

Figure 3.8: Other bands which have become available in the UK for nationwide mobile use [Source: Ofcom,[54] 2022]

Bands	Assignment approach (date)	Licence type and duration	Permitted technology	Acquisition by MNOs
3605–3689MHz and 3925–4009MHz	Administrative assignment (1992)	Single licence (exclusive nationwide) Indefinite duration (subject to ALFs)	Initially assigned for FWA use In 2014, licences were varied to shift the lower range to 3600–3680MHz and allow mobile use in this range.[55] In 2019, licences were varied to allow 5G use[56]	Through various private transactions,[57] the licence was acquired by UK Broadband (UKB) in 2010 Three acquired UKB in 2017

53 In particular, Ofcom awarded (in some cases via auction) several bands for FWA use. These licences did not permit mobile use, but Ofcom has subsequently varied some of the licences (or is considering doing so) to allow mobile use. For example, these include the 3.4GHz band (auctioned in 2003 – shown in Figure 3.8) and the 28GHz band (auctioned in 2000, and again in 2007 along with several other high-frequency bands including the 40GHz band, which is now being considered for 5G mobile use).

54 https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive, https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/mobile-wireless-broadband/below-5ghz

55 https://www.ofcom.org.uk/__data/assets/pdf_file/0014/130253/Statement-UK-Broadbands-spectrum-access-licence-3.6-GHz.pdf

56 https://www.ofcom.org.uk/__data/assets/pdf_file/0029/153839/statement-3.4ghz-3.5ghz-and-3.6ghz-licence-variations.pdf

57 Paragraph 2.5 of Ofcom's decision on the licence variation states: "The UKB Licence was initially administratively granted in 1992 by the Radiocommunications Agency (one of Ofcom's predecessors) to Millicom, on the instruction of the relevant government minister at the time. [...] The licence was traded several times during the 1990s, eventually to a company called GX Networks. In 2003, Pipex Communications (which subsequently changed its name to Freedom4) acquired GX Networks. Freedom4 then sold the licence to UKB in 2010."

Bands	Assignment approach (date)	Licence type and duration	Permitted technology	Acquisition by MNOs
3.4GHz (3.48–3.5GHz and 3.58–3.6GHz)	Auction (2003)	Exclusive regional licences, which were eventually merged into a single national licence[58] Initially 15 years, expiring in July 2018 In 2014, a licence variation for indefinite duration was granted (with ALFs due from July 2018)[59]	Initially auctioned for FWA use In 2007, a licence variation was granted allowing mobile use[60] In 2019, licences were varied to allow 5G use[56]	UKB acquired the majority of the regional licences at auction, and the outstanding licences through private transaction; these were then merged into a single national licence MNO Three acquired UKB in 2017
L-band (1452–1492MHz)	Auction (2008)	Exclusive nationwide licence Indefinite with 15-year initial term (with ALFs after end of initial term)	Initial technical conditions set certain limits on power and density of transmitter deployment In 2015, Ofcom varied the licence to be technology neutral, allowing supplementary downlink (SDL) mobile use (suitable for 4G/5G)[61]	All lots in the auction were won by Qualcomm, which sold the spectrum to MNOs Vodafone and Three (a 20MHz unpaired block to each) in a private transaction in 2015[62]

Accordingly, the total spectrum licensed for public mobile use on a nationwide basis is shown in Figure 3.9 overleaf.

The full set of frequency bands used by public mobile technologies worldwide today is included in specifications published by 3GPP, although not all of the 3GPP-defined bands are used in the UK.

58 In June 2003, two 20MHz TDD blocks (3.48–3.5GHz and 3.58–3.6GHz) were made available under a single licence in each of 15 regions; the 15 regions collectively covered the entirety of the UK. Poundradio (which changed its name to UK Broadband (UKB) shortly after the auction) won licences in 13 out of the 15 regions. It subsequently acquired the remaining two licences by buying the companies (Red Spectrum and Public Hub) that won them in the auction. In March 2007, Ofcom agreed to combine UKB's licences into a single nationwide licence. Later in 2007, UKB successfully requested a variation to its licence conditions to allow technology and application neutrality (thereby allowing mobile as well as FWA use). See https://www.ofcom.org.uk/consultations-and-statements/category-2/uk-broadband-licence

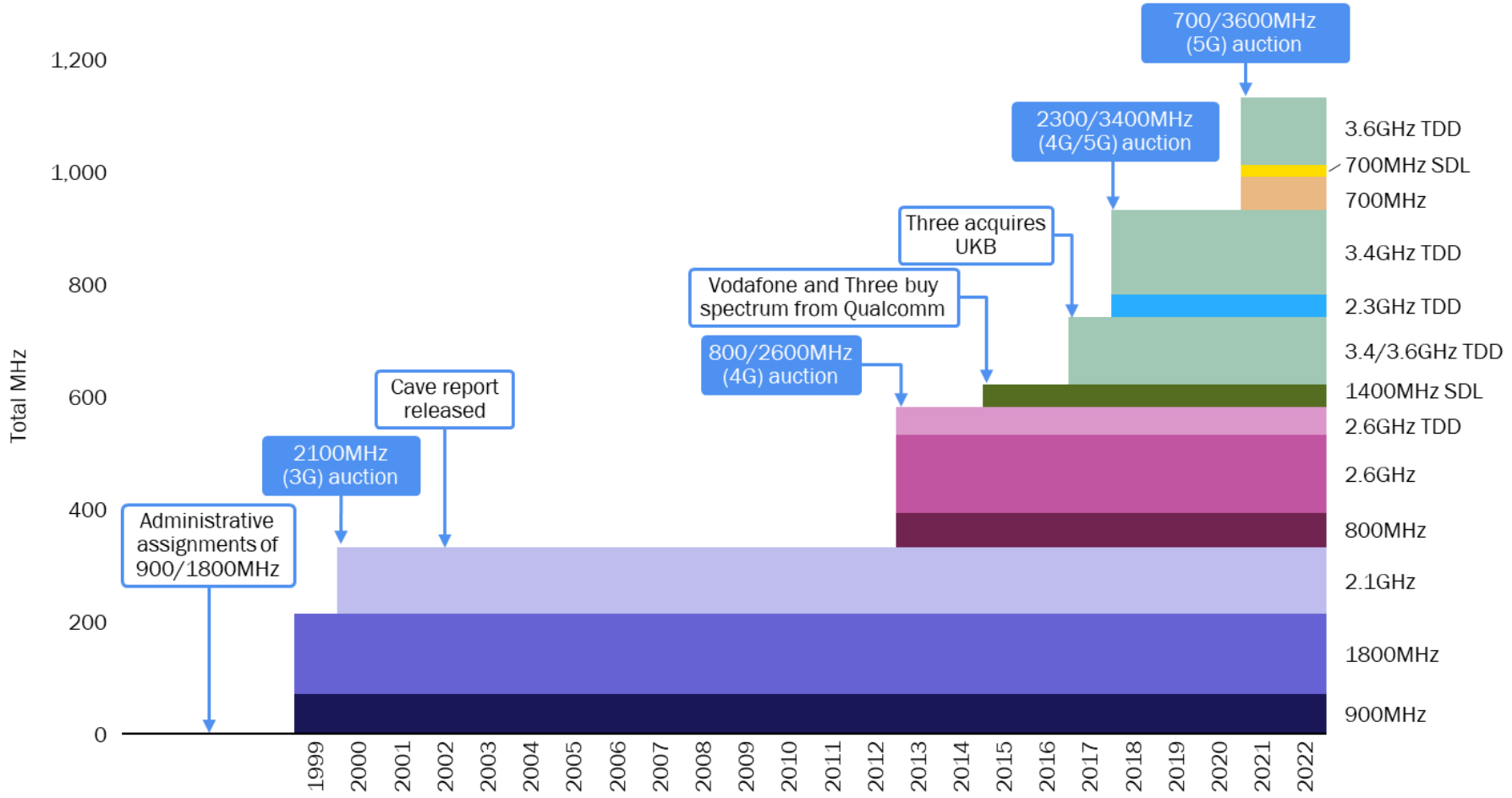
59 https://www.ofcom.org.uk/consultations-and-statements/category-2/uk-broadband-licence

60 https://www.ofcom.org.uk/consultations-and-statements/category-1/bb_application

61 https://www.ofcom.org.uk/consultations-and-statements/category-1/licence-variation-1.4ghz?showResponses=true

62 https://www.qualcomm.com/news/releases/2015/08/qualcomm-agrees-sell-uk-l-band-spectrum-vodafone-and-h3g

Figure 3.9: Total spectrum assigned for public mobile use on a nationwide basis over time[63] [Source: Analysys Mason, 2022]



63 The 20MHz of 2100MHz unpaired spectrum (intended for 3G TDD technology deployment) assigned in the 2000 auction is unused for the provision of mobile and has therefore been excluded from Figure 3.9. We have included the entire 2.6GHz band, including the unpaired portion, but note that the upper and lower 5MHz of the unpaired portion are unusable for high-power base stations, to avoid interference with the 2.6GHz paired band. (A further 5MHz within what is now VMO2's holding was designated as a guard band between the two 2.6GHz unpaired licensees, but Ofcom has recently removed this restriction.)

Future assignment of spectrum for potentially nationwide or wide-area mobile use

A number of other bands are under consideration for future mobile use:

- **The L-band extension (1492–1517MHz)** which is harmonised in Europe for downlink-only wireless broadband (SDL). Ofcom confirmed plans to award this band in its 2022 discussion paper on meeting future demand for mobile data.[64] However, no details or timeline have been provided and the award is not mentioned in Ofcom's plan of work for 2022/23.

- Ofcom's 2022 discussion paper notes that the mobile industry is interested in whether the **600MHz and upper 6GHz bands** can be used for public mobile services. Future use of these bands will be under discussion at WRC-23 for which Ofcom is consulting on its preparatory considerations.[65] As discussed in Section 4.2 later, the future of the upper 6GHz band is contested, and it is not yet confirmed whether the band will be made available for mobile use in the UK (and if so, what the licensing arrangement would be).

- Ofcom recently concluded a consultation on assigning spectrum in the **26GHz and 40GHz bands** for mobile use.[66] As discussed in Section 3.2.5, Ofcom proposes auctioning city/town-wide licences in the 26GHz band in high-density locations.

Key implications for market mechanisms

The spectrum available for mobile use now spans multiple frequency bands and while there is still scarcity in bandwidth available in some spectrum (e.g. below 1GHz), spectrum becoming available in 5G high-bands (e.g. 26GHz and 40GHz) is arguably less scarce due to the wider bandwidth available in these higher frequency ranges. An important difference between the lower bands that were being deployed for mobile use when Cave's report was published, and the higher bands that are becoming part of the 5G ecosystem, is that the opportunity cost is zero if the spectrum in question is in excess supply. In practice however, device harmonisation still means that demand is concentrated within bands supported by the 3GPP global mobile standards. Demand for higher bands is also likely to be highest in urban locations where data traffic levels are highest. Auctioning of city-wide licences, which Ofcom is proposing in the 26GHz band, reflects a practical way to enable MNOs to gain the spectrum that they need whilst also allowing opportunity for others to gain spectrum within the same harmonised bands that the MNOs use.

64 Paragraph 5.20, https://www.ofcom.org.uk/consultations-and-statements/category-3/discussion-paper-meeting-future-demand-for-mobile-data

65 https://www.ofcom.org.uk/consultations-and-statements/category-1/call-for-input-uk-preparations-for-wrc23

66 https://www.ofcom.org.uk/__data/assets/pdf_file/0027/237258/mmwave-spectrum-condoc.pdf

3.2.4 Assignment of spectrum for local and shared mobile use

In 2019, Ofcom introduced shared access and local access licensing frameworks, allowing a wider range of users to gain access to radio spectrum for mobile use in the UK.[67]

Key implications for market mechanisms

The local access licensing initiative could improve the economic efficiency with which mobile spectrum is being used, as well as increase spectrum utilisation. The shared and local access licensing initiatives could help to address concerns that market mechanisms are not delivering high-value mobile spectrum for innovators in the UK.

► *Shared access licences*

Shared access licences were introduced by Ofcom in 2019 to facilitate local wireless connectivity applications. Shared access licences can be either low or medium power and are available in four spectrum bands, as shown in Figure 3.10.

Figure 3.10: Shared access bands available in the UK [Source: Ofcom,[68] 2019]

Shared access band	Available frequencies	Details
1800MHz	2×3.3MHz (1781.7–1785MHz and 1876.7–1880MHz)	Portion of the 1800MHz band not licensed for national mobile services
2300MHz band	10MHz (2390–2400MHz)	Located above licensed national mobile spectrum in 2350–2390MHz
3.8–4.2GHz	390MHz (3.8–4.2GHz)	Located above licensed national mobile spectrum in 3.6–3.8GHz
Lower 26GHz band	2.25GHz (24.25–26.5GHz)	Currently available for indoor low-power licences only. Ofcom recently consulted on extending shared access use to both indoor and outdoor in (1) the 24.25–25.1GHz range in high-density areas, and (2) the 24.25–27.5GHz range in low-density areas. See later in this section for details

Low-power licences are targeted at industrial and enterprise users that wish to deploy private networks where users have the flexibility to move the base station within the agreed licence area. Medium-power licences consist of a single base station in a fixed location and are suitable for industrial and enterprise uses with larger sites, or for providers of FWA in rural areas. Medium-power networks can also be used for schemes to extend mobile coverage in rural areas (in the 1800MHz and 2300MHz bands). Figure 3.11 below shows the applications which are allowed in each band.

67 https://www.ofcom.org.uk/__data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf

68 https://www.ofcom.org.uk/__data/assets/pdf_file/0035/157886/shared-access-licence-guidance.pdf

Figure 3.11: Allowed uses for shared access bands [Source: Ofcom,[69] 2022]

Uses	1800MHz?	2300MHz?	3.8–4.2GHz?	Lower 26GHz?
Private network	Yes (narrowband)	Yes	Yes	Yes (indoor)
Mobile coverage (rural)	Yes	In certain locations (due to co-existence with other users)	No	No
Mobile coverage (indoor)	Yes	Yes	No	Yes
FWA	No	No	Yes	Yes[70]

Individual applications are submitted to Ofcom and licences are granted on a 'first come, first served' (FCFS) basis, subject to a technical assessment. Licences have an indefinite duration and are renewed annually, with the user paying an annual fee to Ofcom (although shorter licences of less than one year are also possible). Outright total trades (to one user) and concurrent total trades (to two or more users) of shared access licences are permitted. Fees are currently cost-based,[71] although Ofcom's 2019 statement notes that it may choose to review fees once demand trends for licences are evident.

Ofcom's 2019 statement also states that it intends to transition to a DSA approach to shared access licences, supported by a fully automated authorisation database. Pending the implementation of DSA, Ofcom has imposed conditions on the shared access licences intended to ensure the efficient use of spectrum (for example, the requirement to start transmission within six months of the licence start date and to remain operational from that point). Licensees have an obligation to co-operate and not interfere with other users. Ofcom also has the power to change the frequency of licences should it choose to change the use of a band. These measures are intended to ensure spectrum is not blocked to potential new users or more efficient arrangements.

► *Local access licences*

In 2019, Ofcom introduced local access licences (LALs) to allow other users to access spectrum licensed on a national basis to the UK MNOs, in areas where that spectrum is not being used by the MNOs, thus increasing spectrum utilisation.[72] LALs were introduced to support the existing trading framework, which Ofcom noted was primarily being used to transfer rights to spectrum from one user to another, rather than to facilitate sharing between users. LALs are intended to provide a simple way to enable spectrum sharing in rural areas (for the provision of private networks or wireless

69 Table 1, page 3, https://www.ofcom.org.uk/__data/assets/pdf_file/0035/157886/shared-access-licence-guidance.pdf

70 FWA is available through fixed links authorisation, although Ofcom is not encouraging new licences.

71 Cost-based annual fees for the 3.8–4.2GHz band are charged by bandwidth, scaled to an average licence fee of GBP320 for 40MHz. See https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/shared-access

72 https://www.ofcom.org.uk/__data/assets/pdf_file/0037/157888/local-access-licence-guidance.pdf

broadband services, for example). LALs are available for all spectrum bands covered by the Mobile Trading Regulations (i.e. all mobile band licences on a national basis).[73]
Prospective users apply directly to Ofcom for a licence which has a default duration of three years, although longer licence durations may be possible if this is supported by the incumbent MNO. Ofcom will grant the licence unless the incumbent MNO can show that it is using the spectrum in the location requested, plans to do so within the designated timeframe, or it is determined that a local licence would interfere with existing networks. Where the application is successful, a one-off licence fee of GBP950 is payable, which we understand is designed to cover the administrative cost to Ofcom of managing the LAL.

Incumbent and local spectrum users must co-operate and not cause interference to one another's networks.[74] As with other mobile spectrum licences, a local access licensee cannot lease its spectrum to other users, but outright total trades and concurrent total trades are permitted (with Ofcom's consent).

3.2.5 Shift towards higher frequencies

With increasing volumes of mobile data traffic being carried by mobile networks, there has been a shift in spectrum needs. As a result, mobile technology has evolved to use ever-higher frequency bands, better suited to higher levels of frequency reuse and providing greater capacity. Historically, mobile bands have been in the ultra high frequency (UHF) range (below 3GHz), but several much higher frequency bands ('mid band' and 'high band') have been incorporated into the 5G specifications. Mobile spectrum in bands below 1GHz is often now referred to as 'low band'.

The primary band for the launch of 5G globally has been the 3.4–3.8GHz band, referred to as 5G mid-band spectrum, and this spectrum has been awarded in the UK via auctions of nationwide licences. However, other mid bands have also been incorporated into the 3GPP specifications for 5G use in other markets/regions. 3GPP recently announced the addition of the upper 6GHz band into 3GPP specifications. This part of the 6GHz band can be used by the latest generation of Wi-Fi technology (Wi-Fi 6), subject to suitable authorisation in the market in question. Ofcom has yet to decide on the future use of the upper 6GHz band in the UK, although it has decided that the lower 6GHz band will be available on a licence-exempt basis, suitable for use by technologies such as Wi-Fi.

Looking ahead, increased attention is being paid to the possibility of more mobile spectrum becoming available at even higher frequencies, along with greater network densification and bespoke coverage solutions in specific environments (e.g. indoors).

Ofcom's discussion paper on meeting the future demand for mobile data states that, in the longer term, Ofcom will consider several bands for mobile communication services, including for 6G, including in

73 A list of LALs in place as of 1 April 2022 is available at https://www.ofcom.org.uk/__data/assets/pdf_file/0021/222591/local-access-licences.pdf

74 Although there is an obligation on both parties here, the overall emphasis is on protecting the incumbent operator from interference; for example, the MNO can object to the licence being granted if the transmitter would cause interference to nearby deployments.

the **7–20GHz and THz ranges**.[75] Ofcom predicts a timeframe which sees 6G becoming significant in the 2030s, and it is continuing to monitor developments and the impact on spectrum management.[76]

3GPP specifications already incorporate several 'high-band' (or mmWave) spectrum ranges, including the 26GHz and 40GHz bands, both of which were identified for mobile broadband on a global basis at WRC-19. As discussed below, Ofcom recently issued a consultation on assigning these bands for mobile use.

26GHz (24.25–27.5GHz) and 40GHz (40.5–43.5GHz) bands[77]

In the 26GHz band, Ofcom proposes introducing a mix of citywide and local licences:

- In major towns and cities ('high density areas'), Ofcom proposes to[78]
  - assign local licences on a FCFS basis in the lowest 850MHz of the band, using the shared access licensing framework (see previous section), and
  - auction city/town-wide licences in the upper 2.4GHz of the band.
- Elsewhere in the UK ('low density areas'), Ofcom proposes to assign local licences on a FCFS basis for the entire 26GHz band through the shared access licensing framework.

In the 40GHz band, Ofcom is seeking views on whether to vary existing FWA licences[79] to allow mobile use, revoke existing licences and reallocate spectrum alongside the 26GHz band, or to use a combination of these approaches.

Key implications for market mechanisms

The move towards higher-frequency spectrum may mean that assignment and management approaches need to evolve to provide greater opportunities for sharing between mobile and other uses, which might be beneficial from a frequency, and/or geographical, utilisation perspective. Increased use of shared access might create demand for new forms of spectrum management systems, which might have further benefits such as more rapid spectrum authorisation (e.g. spectrum sharing approaches, potentially using database technology, might be used alongside auctions in future). This assumes that MNOs, and other players, will have increased demand for localised spectrum, for which automated spectrum assignments will provide opportunities for more-rapid deployment. The recent AWS announcement relating to rapidly deployable private 5G networks is

75 Although THz spectrum will not be wide area; https://www.ofcom.org.uk/__data/assets/pdf_file/0032/228929/terahertz-spectrum-paper.pdf

76 https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf

77 https://www.ofcom.org.uk/consultations-and-statements/category-1/mmwave-spectrum-for-new-uses

78 Ofcom proposes to "*revoke fixed link licences for the 26GHz band in and around high density areas, giving five years' notice of revocation. Fixed links that operate elsewhere in low density areas would remain in the band. We expect that other existing users of the 26GHz band would be able to coexist with new uses*".

79 Existing licences in the 40GHz band were auctioned in 2007 (alongside the 10GHz, 28GHz and 32GHz bands) for FWA use; https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive

a good example of this – a key use case that the AWS announcement seems to be targeting is the events market, with AWS's pricing based on a short-term (60-day) commitment.

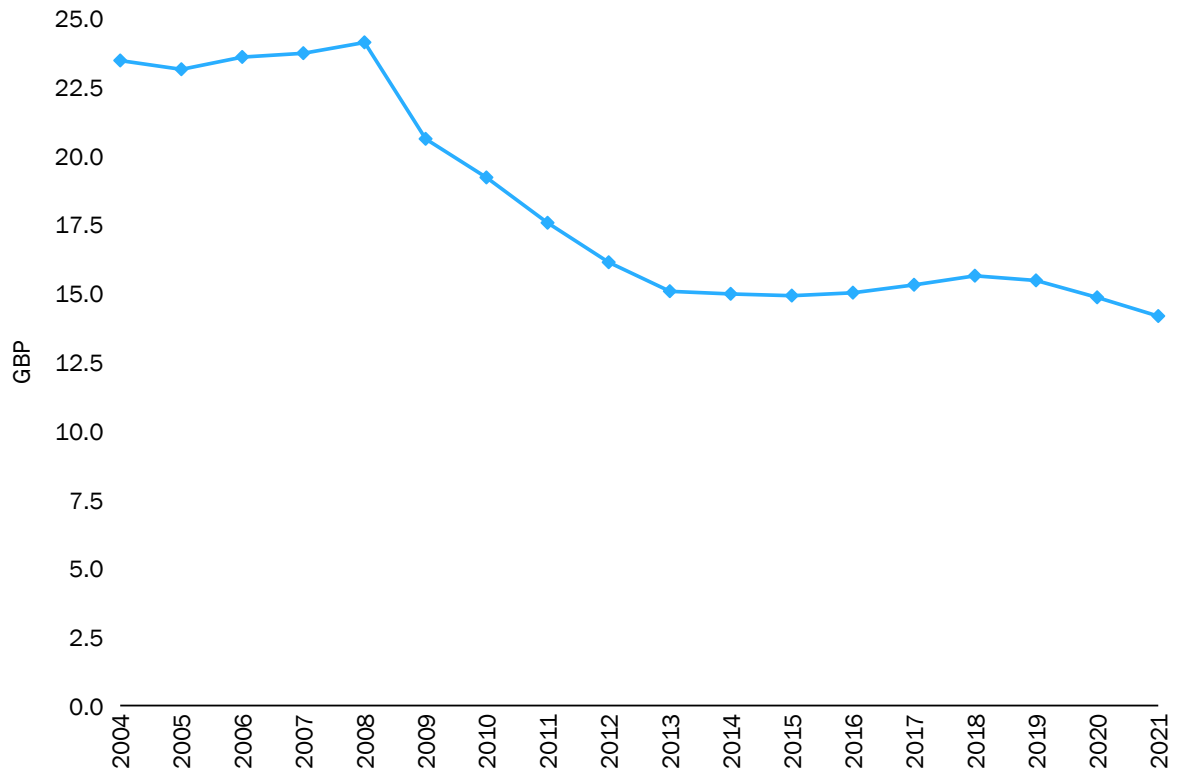
3.2.6 Declining financial returns of MNOs

Average revenue per user (ARPU)

By the time 4G networks were launched (2012 onwards), mobile ARPUs were declining significantly in the UK. Intense price competition, a shift away from voice minute billing to data plans (including unlimited data) and the emergence of multiple mobile virtual network operators (MVNOs) limited MNOs' ability to monetise the introduction of 4G through increased retail pricing.[80] This trend is still evident as 5G as launched.

As shown in Figure 3.12 below, mobile ARPU in the UK has generally declined or flattened in nominal terms in recent years.

Figure 3.12: Historical evolution of mobile market ARPU in nominal terms[81] [Source: Analysys Mason, 2022]



80 The share of total mobile subscribers served by MVNOs has seen steady growth since the Cave report, from around 7% in 2003 to 19% in 2020, although the percentage dropped in 2021 following the merger of VM and O2.

81 ARPU, calculated as the total mobile service revenue (including IoT) divided by the average number of mobile connections (excluding IoT) per month. Total service revenue for mobile services from an operator's own subscribers, as well as from its hosted MVNOs' subscribers. This includes termination (interconnection and roaming-in) revenue.

Noting the above, it is evident that the make-up of mobile ARPU (and MNO revenue) has changed. There has been a fundamental shift from deriving revenue primarily from telephony usage to deriving it primarily from access subscriptions with bundled usage (calls, texts and data). This has led to changes in the shape of MNO network investments, towards requiring additional capacity to offer higher data speeds in urban areas, rather than requiring expanded coverage to capture additional voice traffic in rural areas.

At the same time, the demand for nationwide mobile spectrum licences has become concentrated within the existing four MNOs: in recent auctions of mobile spectrum (e.g. of 700MHz and 3.6GHz licences), the only qualified bidders were the four MNOs.[82]

To date, additional capacity has generally been provided by MNOs through the addition of new frequency bands built onto existing sites (e.g. the most recent capacity upgrade came with the introduction of 5G using the 3.4–3.8GHz band, together with massive MIMO technology). As spectrum becomes increasingly congested, and without significant new mobile spectrum release (at least below mmWave frequencies) expected in the UK market in the remainder of this decade, the investment focus would need to shift to network densification (e.g. greater use of small cells) for adding capacity where technically and commercially feasible.

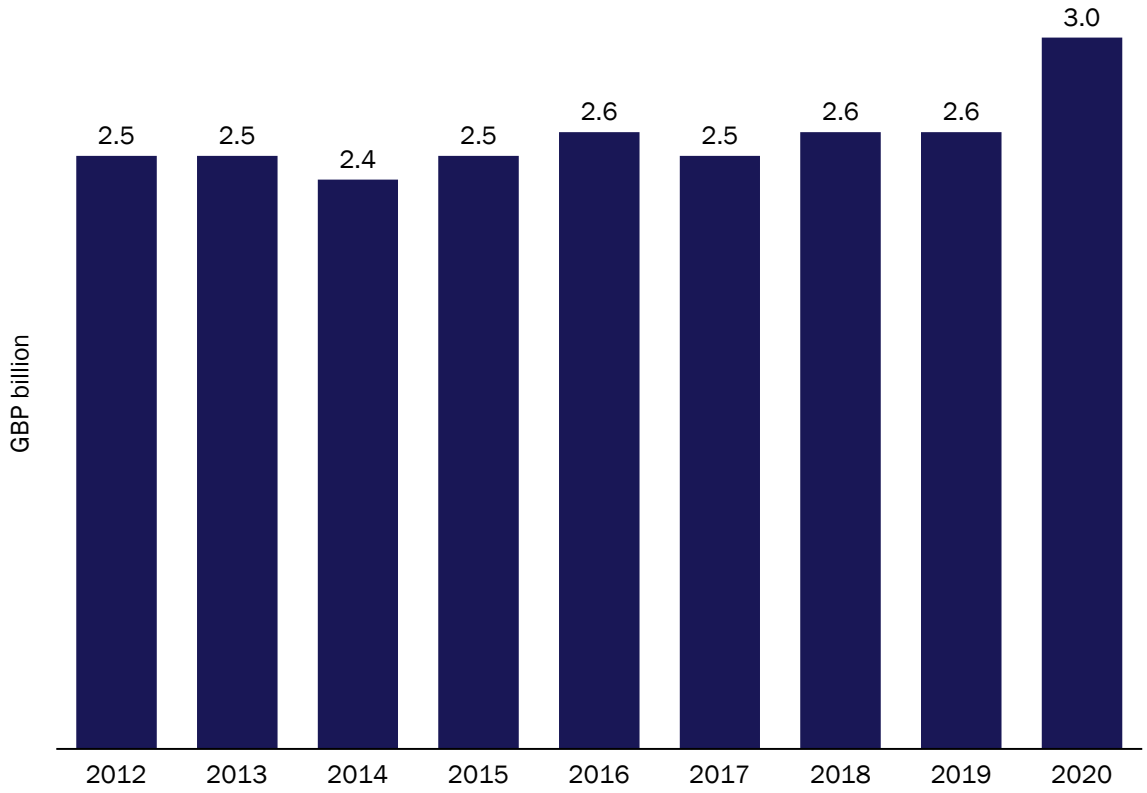
Investment cycles

Along with 4G/5G coverage and capacity expansion, investment over the next few years is expected to be targeted at the deployment of 5G standalone architectures, together with the necessary deployment of more costly higher spectrum bands and the introduction of new technologies in the mobile RAN (for which there are various UK government-led policies, such as relating to acceleration of Open RAN take-up, and removal of high-risk vendors from the 5G estate). These developments will lead to increased investment requirements and further capital expenditure (capex) in future.

However, as shown in Figure 3.13 below, total MNO capex (excluding spectrum acquisition costs) has been relatively flat over the preceding decade. Strong growth in mobile data usage (see Section 3.2.2) has driven the need for MNOs to invest in acquiring and deploying new spectrum to deploy on existing sites. Some deployment of new sites through network densification is also occurring, and the UK MNOs are collectively investing in new macro mobile sites in rural areas through the Shared Rural Network (SRN).

82 We also note that in the 2018 auction, the only non-MNO bidder withdrew at an early stage.

Figure 3.13: Total capital expenditure (excluding spectrum) for UK MNOs [Source: Ofcom,[83] MNOs, 2022]



As shown in Figure 3.13 above, there was a notable increase in MNO capex in 2020, which may be an early indication of increased investment plans/requirements with 5G launch (noting that all four MNOs launched commercial 5G mobile services in 2019/20). Ofcom's 2021 Connected Nations report states that GBP1.8 billion was invested in UK mobile network infrastructure in 2020, a GBP0.4 billion (25%) real-term increase compared to 2019.[84] The largest increase (in percentage terms) was in 5G mobile access network investment, which grew from GBP150 million in 2019 to GBP330 million in 2020. For reference, the total ALF payments due in the UK for 2022 are also around GBP330 million (see Figure 5.5).

Return on investment

As described above, capital investment requirements (for network technology evolution, new sites and densification, excluding spectrum acquisition) have remained relatively stable over the last decade. The main investment driver has been the significant growth in data traffic.

83 Reproduced from Figure 4.2, page 19, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf

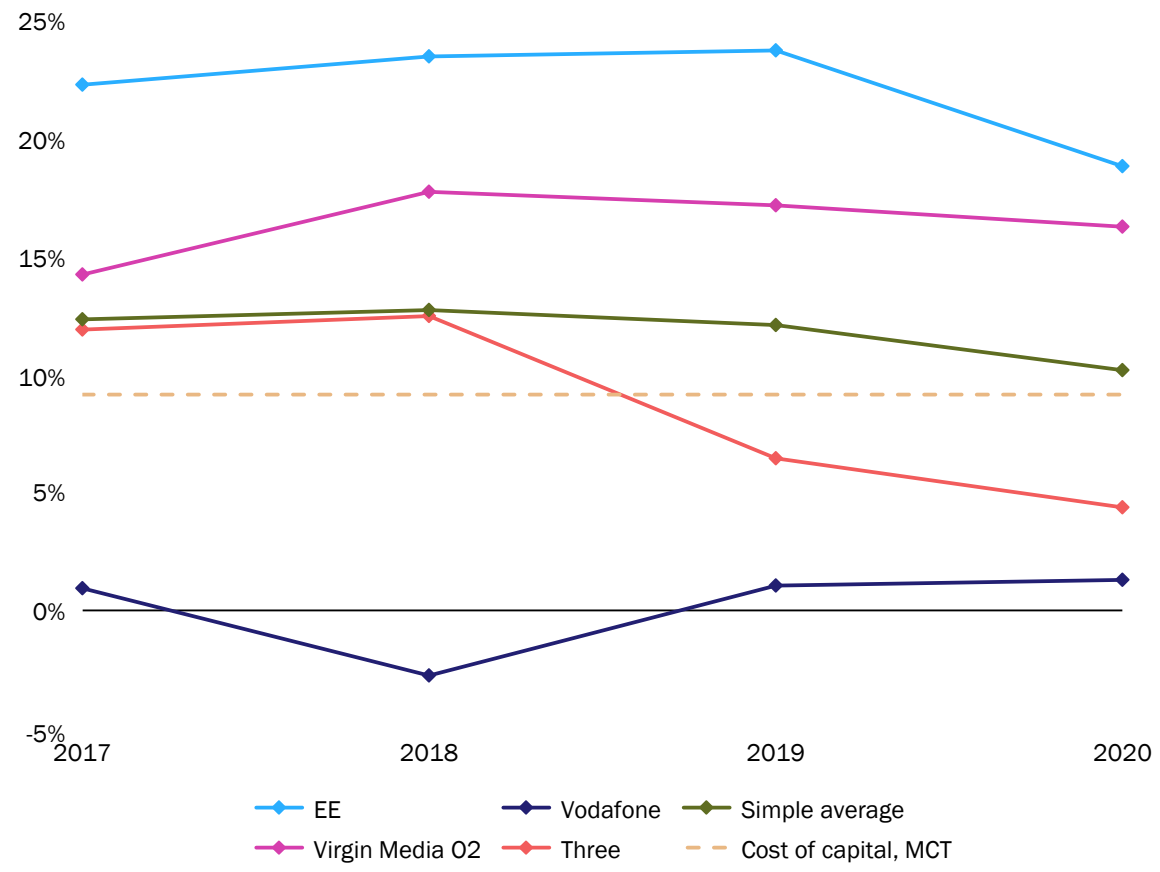
Note that we have rounded values to the nearest GBP100 million. Ofcom's source is company financial statements from Companies House and group financial statements. Capex shown includes non-network-specific capital expenditure (e.g. IT systems/software upgrades, property/facilities and customer-focused capital expenditure).

84 Pages 46 and 47, https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf

To continue to meet data demands, deployment of new sites (either macro sites for coverage, or densification sites for capacity) and upgrading of backhaul capacity will be necessary, but this will increase operational costs for MNOs. Against a decline in retail prices in real terms, this increase in operational expenditure will further reduce the financial returns for MNOs. Given these revenue trends show no signs of reversing, and taking account of the economic climate over the remainder of this decade (e.g. inflationary rises), this is likely to put MNO balance sheets under increasing pressure.

In its 2022 discussion paper on the future approach to mobile markets, Ofcom notes that, "*on an economic basis, average industry return on capital employed (ROCE) has been above the cost of capital but there is significant variation between operators, and our analysis suggests that not all MNOs have covered their cost of capital.*" We have reproduced Ofcom's economic ROCE calculations in Figure 3.14 below.

Figure 3.14: Economic ROCE by MNO, pre-tax nominal [Source: Ofcom,[85] MNOs, 2022][86]



85 "*Ofcom calculations based on publicly available information from financial statements and Ofcom ALF decisions. The cost of capital (pre-tax nominal) comes from Ofcom's charge control decisions for mobile call termination over the relevant period*". See Figure 6.2 from the Discussion paper: https://www.ofcom.org.uk/consultations-and-statements/category-3/ofcoms-future-approach-to-mobile-markets

86 The cost of capital shown is the value used by Ofcom in its most recent mobile call termination decision.

As can be seen, according to these calculations, the UK average industry ROCE is declining (which Ofcom comments is in line with other European mobile markets). Two of the UK MNOs (Vodafone and Three) have a level of return below their cost of capital. As Ofcom notes, "*if ROCE (on an economic basis) was to fall, or was expected to fall, below the cost of capital for a sustained period of time for any MNO, this could dampen its incentive to invest*".

However, Ofcom states that, based on current business plans, "*all MNOs are planning to continue to invest in their networks […] this may be because, while historical returns are useful to consider, expected returns on new investment are more important when considering future investment and capital allocation*". Importantly, Ofcom also states that its latest estimate of the cost of capital is lower than that shown in Figure 3.14, and that any future returns would be compared against this lower benchmark.[87]

We note, however, that Ofcom's discussion paper was published in early 2022, i.e. prior to the recent worsening macro-economic environment and consequent impact on investor appetite for communications. For example, at the time of writing we note that the share price of many major UK telecoms operators has declined by significantly more than the price of wider market indices in recent months. Ofcom's comments also pre-date the large increases in energy costs that are expected to have an impact on industry returns.

Key implications for market mechanisms

Mobile operators are now clearly the highest-value users of the spectrum available for mobile use (a fact which was less certain at the time of the Cave report).

However, low current and projected returns of the four MNOs brings into question the scale of further network investment by existing players, and the viability/survivability of any new players in the UK mobile market. The question of whether further consolidation might occur between MNOs has been raised by stakeholders in the UK market (noting that RAN sharing is already deployed between Vodafone and VMO2, and between BTEE and Three).[88]

In future, consolidation and/or budgetary pressures on UK MNOs may also mean fewer bidders in auctions for new spectrum licences (especially any new nationally available bands to which significant new coverage obligations might apply). However, with the exception of a possible new mobile band at 600MHz (which appears unlikely before 2030 at the earliest, based on draft European positions being prepared for WRC-23), we are not aware of any other new sub-3GHz bands that might be released in the UK (other than the L-band extensions as listed below Figure 3.9).

87 See paragraph 6.16 and 6.17 of the Discussion paper: "*Ofcom's latest view of the appropriate pre-tax nominal cost of capital for a UK MNO has declined based on the latest market evidence and is 7.8% (MCT 2021–2026)*".

88 For example, see https://www.ofcom.org.uk/__data/assets/pdf_file/0034/237499/three.pdf and https://www.mobileworldlive.com/featured-content/home-banner/3-uk-reiterates-consolidation-call-as-ofcom-takes-stock/

We note that the mobile industry is seeking to obtain access to further spectrum in bands above 6GHz on a licensed basis (for example, the upper 6GHz band from 6425–7125MHz is being studied for consideration at WRC-23). The upper 6GHz band is also included in specifications for the latest Wi-Fi equipment, and some regulators outside Europe have made the entire 6GHz band available on a licence-exempt basis. Ofcom has made spectrum available for Wi-Fi use up to 6425MHz, in line with the European Conference of Postal and Telecommunications Administrations (CEPT) decision.[89] The future use of the 6425–7125MHz band, and subsequent European harmonisation decisions relating to this band that might be developed within the CEPT, will be determined based on the outcome of WRC-23.

3.2.7 Coverage roll-out and coverage obligations

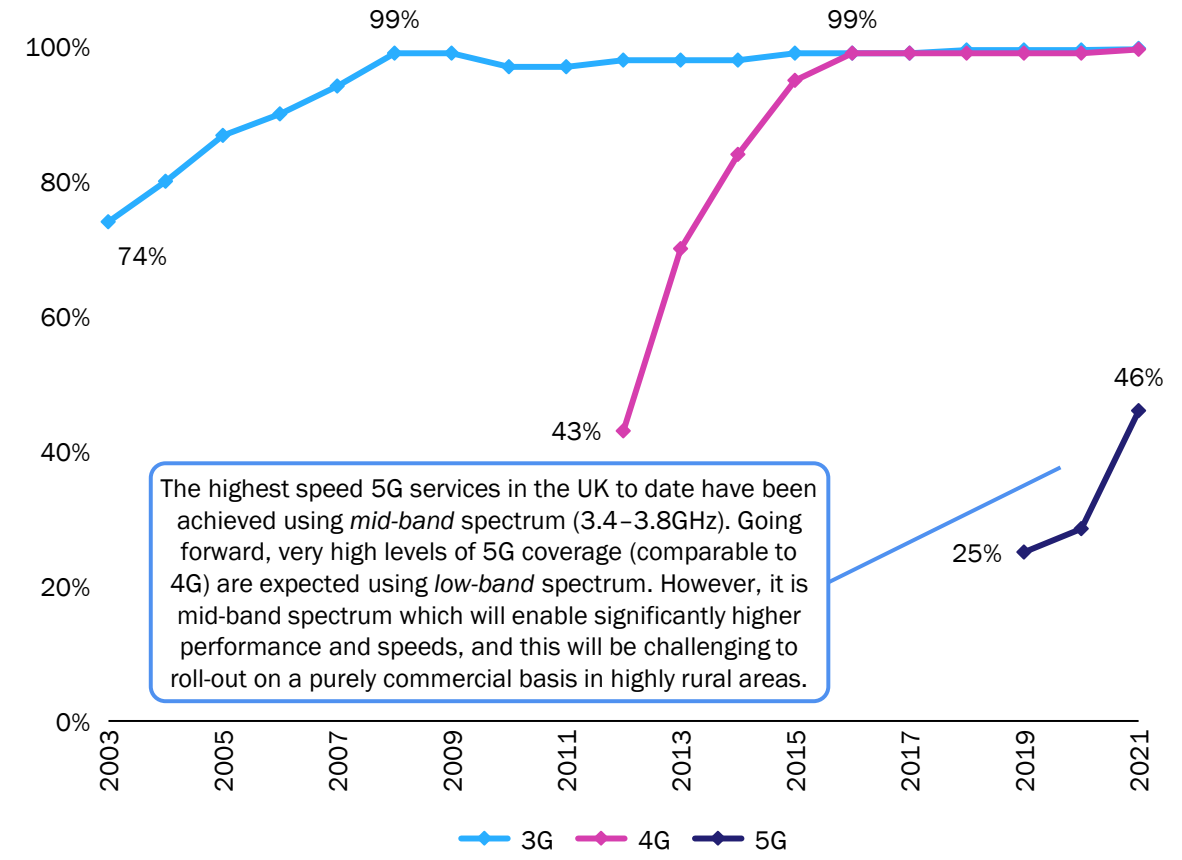
Strong competition in the UK mobile market resulted in rapid expansion of 4G, and has also subsequently supported rapid 5G population coverage.

Figure 3.15 below shows the evolution of UK mobile population coverage over time by technology (3G, 4G and 5G), based on data published by the GSM Association (GSMA). It seems probable that, over the remainder of this decade, 5G networks will reach similar levels of population coverage to that of 4G.[90] However, as noted in Section 3.2.1, this is only likely to be achieved using sub-1GHz spectrum such as the 700MHz band. Whilst this does suggest wide reach of a type of 5G service, with potential benefits in relation to ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC) applications, it will not deliver anything materially better than existing 4G services in terms of mobile broadband applications. On the other hand, 5G services delivered via massive MIMO carriers in the 3.4–3.8GHz band (which will be able to deliver significantly higher speeds and performance) will not be deployed on a commercial basis in highly rural areas: this means that the coverage levels achieved MNOs for 4G (i.e. 99% or more of premises) will not be achieved by ‘full 5G’ without some form of intervention.

89 ECC/DEC/(20)01, see https://docdb.cept.org/implementation/16737

90 We note, for example, that BTEE has announced plans to cover 90% of the UK landmass with 5G by 2028, by using its expanded 4G (SRN) infrastructure.

Figure 3.15: Population coverage by technology over time[91] [Source: GSMA, 2022]



Moreover, there remain more general issues (i.e. not specific to high-speed 5G services but relating to the continuity of mobile coverage more generally) in less populated areas of the UK. How to address 'partial notspots' and 'total notspots' in mobile coverage has been the subject of significant analysis by Ofcom.[92] Even for those rural areas that do have coverage, the capacity (and hence average data speeds) available to users is generally well below that in urban areas. Population distribution in the UK is such that a high percentage of population coverage still leaves significant parts of the UK landmass uncovered (much of the uncovered UK landmass being highly remote terrain, out of reach of power networks as well as fixed, and mobile, networks). The DCMS's call for evidence on wireless infrastructure strategy (published November 2021), sought views from the industry on the level of 5G geographical coverage that the UK might expect to receive by 2027. At the time of producing this report, we understand DCMS is still considering evidence submitted in response to this call for evidence.[93]

91 Coverage by mobile network technology is expressed as a percentage of the total market population, at the end of the period. GSMA's population coverage is calculated based on figures reported by MNOs. The value shown in Figure 3.15 in any given year is the highest of the calculated values/reported values for each MNO.

92 See, for example, the 2021 Connected Nations report; https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf

93 https://www.gov.uk/government/consultations/wireless-infrastructure-strategy-call-for-evidence/wireless-infrastructure-strategy-call-for-evidence

Desire to improve mobile coverage (and quality of mobile coverage) has led to various coverage obligations being imposed on the UK MNOs (see Figure 3.16 below). Most recently, the desire to expand geographical coverage and address partial notspots led to a significant agreement between DCMS and the four MNOs, to improve coverage through a combination of commercial investment and government funding, via the SRN.[94]

Figure 3.16: Coverage obligations that have been imposed on MNOs [Source: Ofcom,[95] 2022]

Summary	Coverage obligation
3G population coverage obligations attached to all MNOs' 2100MHz licences	An obligation to provide 80% of the UK population with 3G coverage by the end of 2007 was attached to each of the 2100MHz licences in the 3G auction. All operators complied with this obligation[96] In 2011, the 2100MHz licences were varied to include a new coverage obligation: 90% population coverage by June 2013, where coverage was defined as a 90% probability that users have a downlink speed greater than 768kbit/s in a lightly loaded cell.[97] The obligation could be met using any spectrum band/technology (i.e. 900/1800/2100MHz – all of which by this time were usable for 3G)[98]
Data population coverage obligation attached to VMO2's 800MHz licence	A coverage obligation was included in one of the 800MHz licences in the 4G auction. This licence was won by O2 (now VMO2) VMO2 was obliged to provide indoor data coverage to 98% of all UK premises by the end of 2017 (95% in each of England, Wales, Scotland and Northern Ireland). Data coverage was defined as a 90% confidence of sustained downlink speeds of at least 2Mbit/s in a lightly loaded network. The obligation could be met using any spectrum band/technology
Voice geographical coverage obligations attached to all MNOs' 900/1800MHz licences	In 2014 (i.e. during the 900/1800MHz ALF consultation process), the government proposed mandating national roaming in order to achieve greater rural mobile coverage.[99] The MNOs were not in favour of this approach, and instead agreed with the government to voluntary geographical coverage obligations, through variations to 900/1800MHz licences. All MNOs agreed to provide voice coverage to 90% of the UK landmass by the end of 2017. The obligation could be met using any spectrum band/technology. In the February 2015 ALF consultation, Ofcom considered whether the new coverage obligation affected the forward-looking market value of the 900/1800MHz spectrum and concluded that it did not[100]

94 https://www.gov.uk/government/news/shared-rural-network

95 https://www.ofcom.org.uk/spectrum/information/cellular-coverage, https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/mobile-wireless-broadband/below-5ghz

96 https://www.ofcom.org.uk/__data/assets/pdf_file/0031/58891/condoc.pdf

97 https://www.ofcom.org.uk/__data/assets/pdf_file/0027/73854/statement.pdf

98 See Figure 3.7 for further details on the variation of 900MHz and 1800MHz band licences for 3G.

99 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/370808/formatted_condoc_final.pdf, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/412618/Government_Response_FINAL__1_.pdf

100 https://www.ofcom.org.uk/__data/assets/pdf_file/0022/83146/annual-licence-fees-900MHz-1800-further-consultation.pdf

Summary	Coverage obligation
Shared Rural Network (SRN)	Ofcom consulted on attaching coverage obligations to the 700MHz band in the combined 700/3600MHz auction in 2021.[101] However, this approach was abandoned in favour of the SRN Under the SRN, all MNOs have committed to providing a 'required service' to 88% of the UK landmass by June 2024 and 90% by January 2027.[102] The required service must have a 95% confidence of sustained downlink speeds of at least 2Mbit/s and be capable of 90-second voice calls without interruption. Various commitments to cover roads and premises also apply. 900MHz and/or 1800MHz licences were varied in 2020 to include the SRN coverage obligations. The obligations can be met using any spectrum band/technology

Key implications for market mechanisms

Improving the availability and consistency of mobile coverage is a primary focus of government policy via DCMS. This raises the question of whether market mechanisms could or should align with government policy in this area (for example, to support coverage roll-out in some way through auction design or ALFs focused on network investment obligations).

3.2.8 Net neutrality regulation

Over the past decade, use of the internet has grown dramatically, including a significant increase in use of mobile devices (e.g. smartphones and tablets) for accessing internet services over mobile networks (see Section 3.2.2). Not all of the data traffic arising from internet use via smartphones and tablets is carried by mobile networks, since Wi-Fi technology is integrated into most smartphones and tablets, meaning that many UK users within the range of a Wi-Fi connection are likely to access the internet via a Wi-Fi connection attached to a fixed broadband network. In the home environment, for example, the majority of internet traffic generated by mobile devices may be carried via Wi-Fi and broadband networks rather than using the MNO networks. Notwithstanding the widespread use of Wi-Fi, it is also the case that large portions of data traffic carried by MNOs are generated from the use of online applications (either data services or video).

Many regulators globally have sought to protect the freedom of internet users by allowing users, rather than internet service providers (ISPs), to control what can be accessed and done online. The European Union's (EU's) 2015 net neutrality (or 'open internet') regulation came into force in the UK in 2016.[103] The core aims of the regulation are to "*safeguard equal and non-discriminatory treatment of traffic in the provision of internet access services and related end-users' rights*" and to "*guarantee the continued functioning of the internet ecosystem as an engine of innovation*".[104]

101 https://www.ofcom.org.uk/consultations-and-statements/category-2/coverage-obligations-in-the-700-mhz-and-3.6-3.8-ghz-spectrum-award

102 Note that the deadline was changed to January 2027 (from June 2026). See https://www.ofcom.org.uk/spectrum/information/cellular-coverage

103 https://www.legislation.gov.uk/uksi/2016/607/regulation/12

104 https://www.legislation.gov.uk/eur/2015/2120/2020-12-21

When the transition period for the UK leaving the EU ended in 2020, the EU net neutrality rules (with certain amendments) became part of UK domestic law.[105] Under the rules, ISPs (including MNOs) must adhere to certain standards concerning open internet access and traffic management, specialised services and transparency. Ofcom is responsible for monitoring and enforcing net neutrality rules and has published the frameworks used for assessing zero rating offers and traffic management measures.[106] Ofcom is also required to publish an annual report of its findings.[107]

The last decade has seen a rapid rise in the use of over-the-top (OTT) services offered by players such as Netflix, YouTube, Meta, WhatsApp and others. These OTT services, when consumed using mobile devices, generate video and data traffic on the mobile networks. Such services now constitute the bulk of mobile data traffic, and have driven (and continue to drive) the huge growth in data traffic described in Section 3.2.2.

Broadly speaking, the net neutrality rules mean that MNOs are not able to discriminate between different types of traffic on their network (e.g. by charging different rates to different content providers). The rules are unclear as to whether or not MNOs will be to discriminate in relation to different types of use, which puts into question how MNOs will be able to monetise bespoke 5G services designed for enterprise and industrial use (so-called 'network slicing', positioned as an important way that MNOs can innovate and differentiate their 5G services to meet different user needs for network quality and capacity dimensioning).

In particular, revenue generated by OTT services does not flow back directly to MNOs (and so it could be argued that not all of the OTT use is reflected in MNOs' willingness to pay for these network investments, or for spectrum). However, mobile customers use OTT services, which creates a demand for high-quality network access. The MNOs can monetise access, and the more customers they can sell an access service to, the more revenue they can generate. Spectrum enables MNOs to build and operate access networks, so more spectrum helps them to build a higher-quality access network that can serve more customers and generate more revenue. The link between an MNO's valuation of spectrum and the economic benefits that are created is still intact, even if some (or indeed the majority) of the economic benefit does not flow back to the MNO.[108]

In 2021, Ofcom released a call for evidence for a net neutrality review.[109] The review would consider how the net neutrality framework is functioning, with the next five to ten years in mind. MNO

105 https://www.legislation.gov.uk/uksi/2018/1243/pdfs/uksiem_20181243_en.pdf

106 https://www.ofcom.org.uk/__data/assets/pdf_file/0014/148100/ofcom-approach-net-neutrality.pdf

107 https://www.ofcom.org.uk/__data/assets/pdf_file/0028/227485/Monitoring-compliance-with-the-EU-Open-Internet-Regulation_2021.pdf

108 An analogy is a train operator bidding for the rights to use a train track in and out of a city. It is what people do in the city that generates economic value, rather than them taking the train journey. But the fact people need to get in and out of the city to generate this economic value means they need a train service, and will pay for it. Hence the train operator can afford to buy/lease access to the track, because it can be monetised. What people do once they are in the city is largely irrelevant to a train operator's business, beyond the fact that if there are a lot of things to do (for which there is high demand), this means a lot of people will have high willingness to pay for access.

109 https://www.ofcom.org.uk/consultations-and-statements/category-2/call-for-evidence-net-neutrality-review?showall=1?showall=1

consultation responses showed support for the core principles of the open internet, while emphasising the need for reform of the current regulations.[110]

Key implications for market mechanisms

The rise of OTT players and the introduction of net neutrality rules is a major change in the market, which creates uncertainties for MNOs over whether investments can be monetised when deploying the most advanced 5G services via network slicing. However, although this issue is the subject of considerable debate within the mobile market, we do not consider this dynamic to have a specific bearing on the suitability of the market mechanisms as applied to mobile spectrum. It does, however, compound the points discussed earlier in this section regarding uncertain return on investments in the latest mobile technologies.

110 These regulations were labelled as outdated, complex and overcautious, and therefore acting as a barrier to investment and innovation. A recurring argument was the need to level the playing field between ISPs and OTT service providers, with the current regulation strongly focused on the access layer. MNOs called for more-flexible regulation which would allow providers to suit connectivity to specific devices and services (particularly relevant with the emergence of 5G capabilities such as network slicing and edge computing). Transparency would be central to this new approach to net neutrality, providing users with the information required to choose between providers. Ofcom has yet to comment on the responses received or outline any next steps.

4 Future direction of the mobile market

In this section we discuss the future direction of the mobile market in the UK:

- Section 4.1 summarises (from Section 3.2) what we consider to be the key market changes since the Cave report, as well as their forward-looking implications that may motivate consideration of changes to the market mechanisms
- In Section 4.2 we discuss considerations relating to light licensing and licence-exempt spectrum
- In Section 4.3 we summarise our views on the suitability of the current approach to market mechanisms for the future wireless market.

4.1 Summary of key future changes

As discussed in the previous section, mobile operators are now clearly the highest-value users of the spectrum that has been made available for public mobile use in the UK (a fact which was less certain at the time of the Cave report). This calls in to question whether AIP set at full market value is required to promote economic spectrum efficiency. Significant further evolution is anticipated in the mobile market over the remainder of this decade, which may motivate broader changes to the market mechanisms as currently applied to mobile spectrum.

Summarised below are what we consider to be the key market changes (as discussed in the previous sections of this report) that may motivate consideration of changes to the market mechanisms.

- **MNOs will continue to see decreasing returns on invested capital if retail prices continue to decline in real terms** – these trends are expected to continue, which will leave MNO balance sheets under pressure.

- The global convergence of mobile technologies within 3GPP to effectively one common RAN standard means that **there have been less marked differences in technical spectrum efficiency between MNOs in recent generations of mobile deployment** than might have been the case if different MNOs had chosen to deploy different radio technologies. Although 5G networks are still being rolled out, MNOs in the UK are following broadly similar paths, deploying a combination of 5G TDD technology in 3.5GHz spectrum together with 5G FDD in lower bands. The definition of future mobile technology generations is unclear, but assuming 3GPP defines any future generation as being built upon current mobile architectures it can be assumed that there will continue to be very limited differences in technical spectrum efficiency between MNOs. However, despite using the same technology, the way that networks are deployed varies across MNOs, with the UK MNOs each having different network footprints, site grids and capacity levels, which may have an impact on the economic spectrum efficiency of use by each MNO.

- **Trading of mobile spectrum is now implemented in all nationally assigned mobile bands**, calling into question whether ALFs are still necessary in these existing bands for promoting

economic efficiency. Certain future bands that might be available for mobile use might not be available on a nationwide basis, and MNOs might not prioritise additional spectrum on a nationwide basis either.

- Large barriers to entry, combined with strong competition among MNOs and retail competition from MVNOs, means that **it is now highly unlikely that a new entrant will successfully bid for nationwide mobile spectrum at an auction in the UK**. In future, this may mean fewer bidders in auctions for new nationwide spectrum licences (especially any new nationally available bands to which coverage obligations might apply, which are unlikely to be viable for new players to meet). This may suggest that alternative licensing approaches such as regional or local licensing, and use of shared spectrum, might be considered in certain situations as a means of encouraging innovation by alternative players.

- **The emergence of demand for self-provided 5G allows for innovation in terms of how technologies might be deployed** (i.e. private 5G networks utilising the spectrum that Ofcom has set aside for this use, from 3.8–4.2GHz). The availability of this spectrum on a set-aside basis raises the prospect for development of new business models and new types of players in the mobile market. It is by no means clear how widely private 5G networks will be deployed in the UK (given that viable alternatives, such as Wi-Fi, might provide similar functionality to that of an on-campus 5G private network). However, there is expected to be increasing demand for access to spectrum in localised areas in future. This in turn might drive creativity and innovation. The MNOs themselves might have greater incentive to innovate in response to heightened competition from internet players and alternative deployment options, such as private 5G or Wi-Fi.

- **Operators are already announcing future capital investment plans** such as further investment in 5G roll-out, and migration to virtualised, 5G standalone, architectures. New RAN technologies such as Open RAN are being actively developed and trialled, albeit in limited (mainly non-urban) locations so far. Early-stage discussions are also underway into 6G concepts and spectrum (with a particular initial focus on identifying spectrum in the 7–20GHz range), although the concepts are currently broad, and some aspects (e.g. sub-THz radio) would represent significant departure from current MNO deployments. However, assuming 6G technology is commercialised around the end of this decade and assuming commercialised technology is suitable for MNO deployment, this suggests further significant capex spend from MNOs from 2030 onwards, alongside increased cost reduction pressures.

- **Fundamental changes in the way mobile technologies are designed (such as Open RAN) might give MNOs further options for innovative deployment**, creating potential for greater diversity, new business models and less capital-intensive deployments, although such changes may take some years yet to implement. Furthermore, it is not yet clear whether Open RAN will have an impact on the structure of the UK mobile market, although it is possible that there will be greater incentive for MNOs to innovate through Open RAN, virtualisation and other related technology developments in response to disruption from internet players and others.

- **The introduction of local access licences has enabled smaller players to access mobile spectrum on a local basis in areas where it is not being used by MNOs**. This can improve the economic efficiency with which mobile spectrum is being used, as well as increase spectrum utilisation. Shared access licences have also allowed smaller players to access spectrum on a local basis in various other bands.

- **The move towards higher-frequency spectrum may make auctions (especially for nationwide assignments) less relevant and increase the importance of spectrum sharing approaches, potentially including dynamic sharing approaches**.

- **Growth in the use of OTT services** has been a major change in the market in recent years. These services are driving strong growth in mobile data traffic (both over mobile networks and using other wireless technologies such as Wi-Fi), but in the eyes of MNOs, OTT players do not face the economic cost of carrying the mobile data traffic that their services create. Mobile video traffic already makes up a significant portion of the traffic carried by mobile networks, and in future real-time video applications alongside augmented reality / virtual reality (AR/VR) applications will account for significant levels of traffic. However, as discussed in the following section we do not consider that this dynamic has a significant impact on the suitability of the market mechanisms as applied to mobile spectrum.

4.2 Considerations relating to lightly licensed, locally licensed and licence-exempt spectrum

Short-range low-power radio uses such as Wi-Fi and Bluetooth are generally deployed in spectrum that is exempt from individual licensing. Given that licence-exempt spectrum can be used by any device or system conforming to the relevant technical requirements, there is in theory no scarcity. The trade-off between using licence-exempt rather than licensed spectrum is generally that strict power limits apply to licence-exempt spectrum, there is no guarantee of spectrum access, and localised congestion can occur. However, the services provided using licence-exempt spectrum can compete with some of the mobile data services offered by MNOs (using licensed mobile spectrum). For example, a factory deploying a wireless system could potentially opt for Wi-Fi as a cheaper option than installing a 5G system for which it would have to acquire a spectrum licence, or a 5G service from an MNO or third party (even though the capabilities of the different systems are not identical).

More generally, wireless connectivity within homes and offices in the UK is widely carried by Wi-Fi routers connected to fixed broadband networks, which are widely available. Whilst the Cave report assumed the opportunity cost for licence-exempt spectrum would be zero (on the basis that interference is so localised that different spectrum users impose no material constraints on one another's transmissions), rising demand for Wi-Fi in homes and other settings has led to congestion in the bands that Wi-Fi has traditionally used. The Wi-Fi industry has also standardised the latest generation of Wi-Fi technology: Wi-Fi 6 (i.e. IEEE 802.11ax), designed for operation in the 6GHz band. The Wi-Fi 6 standard will have options to use wider contiguous channels to cater for more-

advanced connectivity (e.g. AR/VR) than is provisioned within the existing 2.4GHz and 5GHz Wi-Fi bands.

The future use of the upper 6GHz band is a complex debate that is taking place in the UK and in other markets at the time of preparing this report. In the UK, Ofcom originally proposed to add the upper 6GHz band to the shared access licensing framework (for low-power, indoor use), but it subsequently decided not to proceed on this basis, based on consultation responses. In particular, Ofcom notes that there are conflicting views on future use of this band, between those in favour of using the band for higher-powered licensed mobile networks and those favouring low-power, licence-exempt use.[111]

Our view is that it will be difficult to reach a decision on future use of the upper 6GHz band based on market demand alone. On the supply side of the market, Wi-Fi 6 equipment already exists, and regulators in a few markets outside Europe have already opted to make the entire 6GHz band available on a licence-exempt basis, suitable for low power, Wi-Fi type use. In Europe, regulators including Ofcom have made additional spectrum available for Wi-Fi type use in the lower part of the 6GHz band. On the other hand, 3GPP has already incorporated the 6GHz band into its 5G technical specifications via new radio bands n96, n102 and n104, defining the band plan, system parameters (including channel bandwidth), as well as other technical characteristics for licensed mobile use.[112]

The feasibility of a more-flexible licensing approach combining both types of use (i.e. licensed mobile and licence-exempt) is one method to consider. This sort of approach could, for example, be similar to the USA's three-tiered CBRS approach. As described in Section 3.2.1 earlier, the CBRS approach uses databases to manage access for the lower two tiers. However, shared access without databases (e.g. similar to Ofcom's local licensing approach) might also serve the same purpose, albeit relying on Ofcom's issue of licences rather than authority to operate via a third-party database system.

Similar to licence-exempt spectrum, local licensed spectrum, and/or lightly licensed spectrum is not subject to the same market mechanisms as licensed mobile spectrum. Light licensing has been an approach used by Ofcom to make spectrum available for fixed terrestrial use in some bands. The light licensing approach has not been used extensively for mobile spectrum, but the local licensing approach in the 3.8–4.2GHz band, along with the 1800MHz shared spectrum band and the 2300MHz shared spectrum band, is similar. For these bands, Ofcom charges an annual licence fee per area or per base station. Fees are currently set at a low level, although Ofcom has indicated it may consult on proposals to change fees if it believes there is evidence to do so (e.g. based on demand).

111 See Ofcom's recent statement on the upper 6GHz band: https://www.ofcom.org.uk/__data/assets/pdf_file/0011/240212/Statement-update-sharing-proposals-upper-6-GHz-band.pdf

112 See the most recent 3GPP technical specifications (TS) for release 17 – at the time of writing, 38.104 V17.7.0 (2022-09)

4.3 Whether the current approach to market mechanisms is suitable in a future wireless market

In conclusion, the discussion above highlights that it is becoming increasingly difficult for Ofcom to meet, and manage, future demands for spectrum through nationwide 'exclusive' licences.[113] We anticipate that the future direction of licensing of mobile spectrum in the UK will increasingly focus on sharing, as a consequence of conflicting demand for spectrum in key bands, particularly at higher frequencies.

In a future market, it can be envisaged that further mobile spectrum might be licensed on a shared (rather than exclusive) use basis, especially for higher-frequency spectrum. This implies that mobile devices could operate seamlessly across frequency bands for which different licensing arrangements would apply. This type of environment might require regulatory action to change market mechanisms in line with a move away from nationwide exclusivity in spectrum use. For example, techniques to manage spectrum access within a shared band (such as channel assignment and interference control) could be needed in mobile devices and in mobile network equipment to enable use of shared spectrum. Depending on the authorisation approach, investment in database technology could also be needed if spectrum access was to be managed via an automated tool.

Actions might also be needed by regulators to ensure that incentives for efficient spectrum use were aligned between different types of use, and that any competition concerns were addressed. Through the set-aside of the 3.8–4.2GHz band for shared access use, Ofcom has already introduced a situation in which spectrum that might be of value to MNOs (on a licensed basis) and can support services that compete (in certain contexts) with those offered by MNOs is available under a licensing approach that is not subject to market mechanisms.

As such, services offered using licence-exempt or lightly licensed spectrum may to some extent compete with services offered using licensed mobile spectrum. The extent of this competition may be limited by the very different technical conditions related to the use of the spectrum. However, to the extent that the services do compete, there may be some distortion of competition as a result of the different basis on which charges for the spectrum are derived. Currently, the UK framework includes AIP-based ALFs in the licensed case, but spectrum is only charged for on a cost recovery basis in the case of lightly licensed spectrum in the 3.8–4.2GHz band, and there is a free-to-use framework in licence-exempt spectrum. The setting aside of spectrum for private deployment therefore carries some risk of disruptive mobile entry and distortion of competition; if that was to occur, then the levelling of fees between MNO spectrum and private 5G spectrum would be one mechanism that could be applied to address this.

113 We generally refer to the nationwide mobile licences issued by Ofcom as 'exclusive', although we note that this is not technically correct. For example, Section 4 of the Information Memorandum for the 700MHz and 3.6GHz auction states that "for the avoidance of doubt the licences will not guarantee exclusive use of the spectrum awarded. In the future, we may grant additional authorisations to allow the use of all, or part, of the spectrum, including the spectrum that is the subject of this award process. Such authorisation may occur, for example, by way of the grant of new licences, decisions as to the variation of existing licences, or decisions as to exemptions from licensing. We would develop and consult on the conditions of use under any such additional authorisations in order to manage the risk of harmful interference". Furthermore, the introduction of local access licences allows other users to access spectrum licensed on a national basis to MNOs in areas where that spectrum is not being used by the MNOs.

Where there is no scarcity of licence-exempt spectrum, there will be no opportunity cost in 'own use'.[114] However, if the spectrum being used could have offered significant value in an alternative use (i.e. on a licensed basis) then the opportunity cost could potentially be significant. In the absence of AIP-based ALFs, which are in any case impractical for licence-exempt spectrum and potentially undesirable for lightly licensed spectrum, the spectrum users would not face this opportunity cost, potentially leading to the aforementioned distortion of competition. On the other hand, licence-exempt and lightly licensed uses of spectrum may offer significant downstream benefits (e.g. to consumers), which are not of direct value to the spectrum user, and may promote innovation.

The choice of assignment of spectrum bands between licensed, lightly licensed and licence-exempt uses is therefore a complicated one, and the optimal market mechanism approach for lightly licensed spectrum is unclear. These complex issues would benefit from further investigation and analysis.

As noted above, an alternative to using a band exclusively for either licensed, lightly licensed or licence-exempt services is to pursue a policy that seeks to keep options open within individual bands. However, this co-existence can be very difficult to achieve when faced with two technically different deployment types – e.g. high-power, high-tower licensed mobile versus low-power, low-height antennas for private 5G networks and (even more so) for licence-exempt spectrum use. The CBRS-style tiered approach aims to enable both licensed and general access in the same band, through careful management of locations of use. This notwithstanding, we note that where lightly licensed uses do not cause interference, the local access licensing scheme that Ofcom has put in place already looks to achieve this kind of tiered outcome in spectrum licensed to UK MNOs.

Despite the increased role of spectrum sharing, our conclusion is that standard economic arguments in favour of market-led approaches suggest that some form of auctions and trading should continue to be considered in the context of licensed mobile spectrum. We note that some aspects of mobile licensing linked to shared use (specifically, rights of use) must be unambiguously defined for shared spectrum, which creates complexities. Some aspects of mobile market mechanisms (specifically licence duration) are also somewhat complex, with trade-offs to be made and different arguments pointing in different directions (e.g. competition concerns may point to shorter licence durations, while the aim of minimising transaction costs may point to longer or indefinite licence durations). As such, the optimal way of implementing each market mechanism is debatable, and we discuss the key arguments in the following section.

We note that the market mechanisms used to manage mobile spectrum will need to evolve as auctions and trading become less useful and shared (potentially dynamic) access increases in importance in the future, especially in higher frequency bands. Careful consideration is needed on the best way to implement this evolution. We would expect nationally licensed bands to continue to rely on the existing mechanisms of auctions and trading. However, we envisage the need for a case-by-case assessment regarding how to assign new bands, particularly at higher frequencies; and where sharing is opted for, there is likely to be a need to rely on new authorisation mechanisms, with existing mechanisms like auctions playing a less prominent role.

114 A term used by Ofcom to describe the opportunity cost imposed by others using the spectrum in the same way.

5 Assessment of effectiveness of the market mechanisms

In this section we review the basis for the current approaches to market mechanisms (i.e. trading, auctions and pricing) as applied to mobile spectrum, and possible arguments against the market mechanisms as currently implemented. We then briefly consider potential distortions of competition in relation to other spectrum to which market mechanisms may not be applied. We focus only on the arguments which we consider to have the greatest merit (and/or are most frequently made). Annex A provides a fuller list of arguments, initially collated by techUK, which provided a key input to this study.

5.1 Trading

5.1.1 Overview

Following a consultation on implementing spectrum trading in July 2002,[115] the Wireless Telegraphy (Spectrum Trading) Regulations 2004 came into force in the UK, which allowed trading of various licence types. Ofcom implemented trading progressively across different types of spectrum use, with trading for mobile being introduced several years after trading was first allowed in other non-mobile spectrum.

In December 2010, a government Direction required that Ofcom enable "*the transfer of all or part of the rights and obligations arising as a result of 900MHz, 1800MHz and 2100MHz licences from the licensee to another person*".[116] As a result, Ofcom released a statement in June 2011 setting out its proposal to make licences for these bands tradable. This was followed by a new set of regulations specific to the trading of public wireless networks (PWNs) and some spectrum access licences: the Wireless Telegraphy (Mobile Spectrum Trading Regulations) 2011.[117] All mobile spectrum that has been licensed on a national basis can now be traded under these regulations.

Types of trading permitted

Under the Mobile Spectrum Trading Regulations, different types of 'transfer' (i.e. trades) are permitted. Transfers can be outright or concurrent, and total or partial (giving a matrix of four possible types of trade).[118]

In an **outright transfer** all rights and obligations of the traded licence are passed from the original licensee to the transferee. In a **concurrent transfer**, the rights and obligations of the traded licence

115 Ofcom was established by the 2003 Communications Act and took over from the Radiocommunications Agency, and other agencies, as the national regulatory authority (NRA) for telecoms (including spectrum management) in the UK.

116 https://www.ofcom.org.uk/__data/assets/pdf_file/0024/74652/900-1800-2100-statement.pdf

117 https://www.legislation.gov.uk/uksi/2011/1507/introduction/made

118 https://www.ofcom.org.uk/__data/assets/pdf_file/0029/88337/Trading-guidance-notes.pdf

are shared between the original licensee and the transferee, and applicable to both parties. There is no limit on the permitted number of concurrent licence holders.

In a **total transfer** all rights and obligations of the traded licence are transferred to the transferee and the original licensee surrenders its licence to be cancelled. In a **partial transfer** the licence in question can be partitioned, so that the rights and obligations are divided between the original licensee and the transferee. This results in two separate licences (the existing licence is amended, and a separate new licence is created). Unless restricted by the regulations, the partition can occur on the basis of frequency, geography or time.[119]

Transfers may in principle be permanent or time-limited. However, there is significant complexity associated with a trade being time-limited, as it involves the transferee reversing contractual provisions for the original transaction at a certain point in time. It is also necessary for Ofcom to approve both trades (i.e. the original trade plus the reverse transaction), and so time-limited trading does not offer a full substitute for market-led leasing.

The fact that trading of mobile spectrum is now possible in all nationally assigned mobile bands (which means MNOs can trade their mobile spectrum with other MNOs and/or with other third parties) calls into question whether ALFs are still necessary in these bands for promoting economic efficiency. This issue is discussed in Section 5.3.2.

5.1.2 Transaction costs and other practical issues with trading

From our research conducted for this study, we are aware there may be some practical issues associated with the Mobile Trading Regulations which may create barriers to trading, in the form of imposing transaction costs and/or increasing the complexity of negotiations. For example, when a mobile spectrum licence is traded, all ALFs owed must be paid in full before the trade can occur (including any staged payments).[120] However, we note that this is arguably a problem attributable to ALFs rather than the trading framework.

We note that Ofcom's consent is required to authorise a trade. This process includes gathering information about the trade and the parties involved, followed by a competition assessment. If it chooses, Ofcom may give conditional consent to a trade subject to compliance with particular directions. We are not aware of evidence that Ofcom's competition assessment process is imposing a material or undue barrier to trading. On the contrary, it plays an important role in encouraging a competitive market (by allowing Ofcom to block trades that are likely to harm competition).

119 Partial transfers (with any kind of partition) are allowed for all PWN licences (with the exception of 3925–4009MHz within the 3.6GHz licence class, for which only total transfers are permitted).

120 We note that the ALF payment date remains unchanged, no additional ALFs are incurred, and no repayment of previously paid ALFs is due to the original licensee.

5.1.3 Lack of ability to lease spectrum limits flexibility

In a trade, the licensee passes on all rights and obligations to the spectrum being traded to the new licensee. The process requires Ofcom's involvement to amend/revoke the original licence, and issue a new licence. By contrast, under a market-led lease (of the kind that is possible in certain non-mobile bands), the licensee remains responsible for the spectrum and compliance with the licence, including for any activity undertaken by a leaseholder. Market-led leasing is a commercial matter between the parties that does not involve Ofcom, and no new licence is issued.[121]

This form of market-led leasing is not currently available for licences covered by the Mobile Trading Regulations,[122] although local access licences (discussed in Section 3.2.4) have been introduced by Ofcom, allowing players to access MNOs' nationally licensed spectrum in areas where they are not using it.

Local access licensing has largely addressed the disadvantages of not having a market-led leasing framework. However, there are still cases where some incremental benefit could be offered through the introduction of market-led leasing, which would give MNOs the ability to lease specific frequencies in specific geographical areas for a defined time period, without the involvement of Ofcom.

For example, some innovators may require longer than the three-year default licence term offered through the local access licensing regime, and may be able to agree this commercially with an MNO in a more bespoke manner.[123] There may also be edge cases where an MNO is using (or has plans to use) the spectrum but a local user could derive greater value from it. We note that these situations could alternatively be addressed by Ofcom allowing the MNO to charge a fee to the local licence applicant as a condition of granting permission (where the application would otherwise be rejected).[124]

Although the introduction of market-led leasing (or the ability for an MNO to monetise the granting of local access licence permission in cases where it has a right to deny the application, for example the MNO is already using the spectrum) is unlikely to have a large impact on the volumes of 'trades', these approaches may still lead to some additional exchanges of spectrum, offering an improvement

121 See paragraphs 2.12 and 2.13 of https://www.ofcom.org.uk/__data/assets/pdf_file/0029/88337/Trading-guidance-notes.pdf

122 As discussed in Section 5.3.5, Ofcom recently removed the permission for leasing from UKB's 3600–3680MHz licence, in alignment with the other licences covered by the Mobile Trading Regulations.

123 As explained in Section 3.2.4, the default local access licence duration is three years. Longer licence durations may be possible, but only if this is supported by the incumbent MNO.

124 We understand that it is not clear whether this is currently permitted within the existing local access licensing framework. If MNOs were able to charge a fee to local access applicants as a condition of granting permission (in cases where the MNO would otherwise have a right not to grant permission, e.g. because it has plans to use the spectrum), this would enable a form of time-limited trading. As discussed in Section 5.1.1, time-limited trading is already possible. However, enabling it through the existing local access licensing framework may remove some of the complexity.

in spectrum efficiency. If market-led leasing was introduced, liability arrangements between the MNO and the leaseholder would need to be carefully considered.

5.1.4 Limited trading of mobile spectrum has taken place to date

Figure 5.1 below shows the trades of national mobile spectrum licences that were recorded in Ofcom's published transfer notification register as of July 2022.

Figure 5.1: Mobile spectrum trades [Source: Ofcom's transfer notification register,[125] 2022]

Year	Description	Buyer	Seller	Status	Spectrum subject to ALFs at time of trade?
2012	As a condition of the Orange/ T-Mobile merger to form EE, EE was required to divest 2×15MHz of 1800MHz spectrum	Three	BTEE	Completed	Yes*
2015	Vodafone and Three acquired a total of 40MHz of L-band spectrum from Qualcomm	Vodafone	Qualcomm	Completed	No
		Three	Qualcomm	Completed	No
2018	Defragmentation of the 900MHz band	VMO2/ Vodafone	VMO2/ Vodafone	Completed	Yes*
2020	EE sold 25MHz of 2.6GHz spectrum to VMO2	VMO2	BTEE	Completed	No
2021	Defragmentation of the 3.4–3.8GHz band following the principal stage of the 3.6GHz auction. VMO2 and Vodafone agreed to trade 40MHz blocks. Both MNOs will have shared access to both blocks until the end of 2025	VMO2/ Vodafone	VMO2/ Vodafone	Completed/ in progress	No

* As discussed in Section 5.3.1, AIP has been applied to the 900MHz and 1800MHz bands since the late 1990s, but was not set to reflect 'full market value' until 2015 (and, due to legal challenge, final values were not set until 2018).

In contrast to the large number of trades of non-mobile spectrum licences, Figure 5.1 shows that only five trades of mobile spectrum licences have taken place to date. Of these, one was a mandated divestment of 1800MHz spectrum (part of the conditions for the Orange/T-Mobile merger in 2010) and two others were to achieve defragmentation (in the 900MHz and 3.4–3.8GHz band). A further defragmentation trade in the 3.4–3.8GHz band is under consideration (see Section 5.3.5).

125 https://www.ofcom.org.uk/spectrum/information/spectrum-information-system-sis/spectrum-information-portal. Note that we have excluded spectrum trades which have taken place by virtue of acquisition, i.e. Three's acquisition of UKB (which held 3.4GHz and 3.6GHz mobile spectrum, as well as higher-frequency FWA spectrum).

It is argued by some that the limited amount of trading of mobile spectrum licences that has taken place provides evidence that the current trading framework is not functioning well or could be modified in some way to perform better. However, in our view, the limited amount of trading[126] may be a result of factors that are not directly related to the trading framework.

- **There are a relatively low number of national mobile licences available for trading**. While mobile spectrum licences can be partitioned by frequency, only certain bandwidths have been standardised in the 3GPP specifications, and small carrier sizes can be inefficient. The low number of licences limits the number of trades that might be expected to take place.

- **There may be strategic incentives for MNOs not to trade**, for example to disadvantage MNO competitors or to foreclose new entrants. While this may well be a dynamic that operates in the market, we do not consider this to indicate any problem with the trading framework as such (and there is no clear modification to the current trading framework that would address this issue).

- **Auctions held in the UK are generally leading to economically efficient outcomes**, such that mobile spectrum is generally already in the hands of its highest-value users (at least initially following auctions).[127] In the few cases where auction outcomes or spectrum assignments have been (or become) inefficient, these have been corrected by the market through trades (e.g. the 900MHz defragmentation trade, and the BTEE/VMO2 2.6GHz spectrum trade). From this perspective, the lack of trades may actually indicate that the market is working well.

- **The existence of ALFs may be presenting a barrier to trading**. This is discussed later, in Section 5.3.5.

In summary, while there may be certain minor issues with the trading framework itself (e.g. the lack of ability to lease and other practical issues, as discussed above), our view is that these are not the reason for the limited number of mobile trades that have taken place.

We note that, to date, all mobile spectrum licences auctioned in the UK (i.e. the 3.6GHz band and below) have been nationwide.

As discussed in later sections, a key market development is the shift to mobile use at higher frequencies, which are more suited to licensing on a regional or local basis. This raises the possibility of more trading of local/regional rights of use in future. It also raises the prospect of sharing between mobile and non-mobile uses on a geographical basis (e.g. if the mobile use is concentrated within urban locations, and other existing or future services use spectrum predominantly outside urban areas, then it may be possible for sharing to occur, thus removing or reducing the requirement for existing services to be relocated).

126 We also note that the UK is in alignment with the rest of Europe in this regard: across Europe, the level of 'high-value' mobile spectrum trades has been low.

127 We note that MNOs may tailor their networks to their spectrum holdings, meaning that existing licensees may be particularly high-value users of the spectrum.

Where licences are issued on a more localised basis for higher frequencies there may be scope for increased volumes of trades or leases at lower value. This could potentially be achieved through a more automated system, which may involve less friction and lower transaction costs, thereby increasing trading volumes.

5.2 Auctions

New spectrum can be assigned to the market through various mechanisms, which can broadly be classified as either competitive or non-competitive.

- **Non-competitive mechanisms** involve direct/administrative assignment ('command and control'), in which the regulator determines who is assigned spectrum. This includes FCFS approaches, in which spectrum is administratively assigned to the first applicant. Direct assignment can also include the requirement for some level of ongoing spectrum management, which can be enabled through administrative co-ordination or, in some cases, through technology approaches (such as databases or DSA).

- **Competitive assignment mechanisms** include:

  – *beauty contests*: spectrum licences are assigned to the applicants that commit to best fulfil specific criteria laid down by the regulator in advance

  – *auctions*: MNOs compete for spectrum licences in an auction, and spectrum is assigned to the MNO that makes the highest bid

  – *hybrid approaches*: certain elements of an auction are combined with those of a beauty contest.

There are some arguments against the concept of auctions, many of which also apply to other competitive assignment mechanisms. For example, although it may be time and resource efficient to release further mobile spectrum in batches through a single assignment mechanism, it could be argued that this delays the deployment timeline for MNOs with ambitions to invest in a particular band as soon as handsets become available (unlike other MNOs that might wait until greater penetration of the latest handsets is achieved).[128] On a related note, it could be argued that the co-ordinated release of spectrum in a given band (creating the impression that MNOs must acquire

128 MNOs' timelines for investment are generally guided by global device and equipment ecosystems, for which there is limited divergence between operators. This means that delays in assigning spectrum that result from the use of an auction process may not result in significant inefficiencies. When auctions are delayed, the impact on efficiency can be greater, but these delays often arise due to litigation, which we consider at least as likely to arise if a non-competitive and less co-ordinated approach to assigning spectrum to individual operators were followed.

spectrum in that band to remain competitive) would contribute to a spike in the value of spectrum at a particular time.[129]

Nonetheless, auctions remain the most commonly used approach for assigning new mobile spectrum (on a national or regional basis) globally to date (and are certainly the default choice in most developed markets). Even in the context of growing government engagement in the security and resilience implications of successful deployment of next-generation mobile infrastructures, auctions which impose requirements on how the spectrum is used (e.g. no equipment from high-risk vendors) remain an appropriate approach.

However, it is important to note that there are alternatives. For example, hybrid approaches have been followed for awarding some new mobile spectrum bands in both France and Denmark.

- In 2020, the French national regulatory authority (NRA) assigned spectrum in the 3.4–3.8GHz band in metropolitan France in a two-stage process. In the first stage, the four MNOs were each offered a block of 50MHz for EUR350 million, in exchange for meeting certain coverage obligations. In the second stage, a further 110MHz (11 blocks of 10MHz) were auctioned at a reserve price of EUR70 million per 10MHz block. This was followed by a separate positioning auction to assign frequencies within the 3.4–3.8GHz band.[130]

- Likewise, the 2021 combinatorial spectrum auction in Denmark (for 1400MHz, 2100MHz, 2300MHz, 3.5GHz and 26GHz) employed a hybrid approach to spectrum assignment.[131] The auction included a first stage where MNOs submitted sealed bids for 2×10MHz lots in the 2100MHz band and 80MHz lots in the 3.5GHz band, subject to specific coverage obligations. There were three 'coverage lots' available in each band and MNOs were able to acquire one lot per band. Winners paid the highest unsuccessful bid, or the reserve price (DKK0 for 2100MHz and DKK75 million for 3.5MHz) if three or fewer bids were received for each category. The second auction stage allowed winners of the 2100MHz coverage lots to bid for specific coverage regions. These initial stages were followed by a combinatorial multi-round ascending (CMRA) auction and a further stage to assign specific frequencies.[132] Similar approaches were also followed in the 2016 auction of 1800MHz and the 2019 auction of 700MHz and 900MHz.

Beauty contests may be simpler and easier to run, but they are less transparent, with the regulator likely to be subject to scrutiny and challenge when judging between applicants. Moreover, they are

129 Our view is that spectrum value is driven by many factors, and it is unclear whether co-ordinated release at a single point in time drives an increase in spectrum value. If spectrum in a band was released in stages, increased uncertainty about the timing of the staged release might lead to price inflation in relation to the initial releases (for example, the 3.4–3.6GHz band was sold for higher auction prices than the technically very similar 3.6–3.8GHz spectrum in the UK, largely because of uncertainty over the availability and assignment of the 3.6–3.8GHz). Staggered release of spectrum could therefore lead both to asymmetry in the prices paid between MNOs and higher overall spectrum prices.

130 https://www.arcep.fr/la-regulation/grands-dossiers-reseaux-mobiles/la-5g/frequences-5g-procedure-dattribution-de-la-bande-34-38-ghz-en-metropole.html

131 While this was formally an auction, in practice the limitation of operators being able to acquire one lot per band in the first stage guaranteed a large amount of spectrum to each operator.

132 https://ens.dk/sites/ens.dk/files/Tele/information_memorandum_1.pdf

more prone to regulatory failure, due to the regulator determining the split of spectrum licences between applicants. These factors may result in significant delays to spectrum being awarded (and hence to networks being deployed), if proposed licence awards are challenged by unsuccessful applicants.

It is noted that auctions can start to approximate administrative assignment processes when bespoke auction rules begin to impose significant constraints on the possible outcomes (e.g. spectrum caps or floors, or large lot sizes, may dictate a certain amount of symmetry in the outcome, or coverage obligations may restrict the feasible winners of certain lots). However, in our view this is more a point relating to the implementation, rather than the principle, of using auctions.

Auctions must therefore be well designed in order to avoid inefficient outcomes. This point is discussed further in Section 5.2.1.

Particular considerations apply to auctioned licences upon licence expiry. The current approach in the UK is for automatic renewal after an initial term, via an indefinite licence, subject to payment of ALFs. This approach is compared to alternative options in Section 5.2.2.

Where demand does not exceed supply (e.g. at higher frequencies in certain locations) auctions may no longer be the most suitable approach for awarding spectrum. This is discussed further in Section 5.2.3.

5.2.1 The impact of auction design on outcomes

Auction formats and rules

A badly designed auction can lead to undesirable outcomes, either for governments or regulators due to delayed network roll-out, or for one or more auction participants (e.g. MNOs) due to not winning spectrum, or winning spectrum that does not match their business requirements. To avoid these pitfalls, spectrum auctions need to be carefully designed. In designing auctions, regulators may also have several policy objectives, which can sometimes conflict with one another.

The choice of format can have an impact on the effectiveness of an auction in achieving the desired policy objectives. An auction process can take several forms, some of which (e.g. first price, sealed bid) can result in unexpected (and potentially inefficient) outcomes. A notable example is the exit of a national mobile operator (Tele2) from the Norwegian market some years ago, when it failed to win sufficient spectrum against competition from a new player.

In the UK, Ofcom has generally taken care when choosing an auction format and setting the rules. The efficient assignment of spectrum is a high priority, and forms part of Ofcom's statutory duties in relation to the management of radio spectrum. However, other policy objectives may include preserving or enhancing competition and coverage whilst ensuring a fair and transparent outcome. These objectives may conflict with efficiency objectives where, for example, a more symmetric

spectrum assignment may be favourable on competition grounds than might be achieved through an open auction format that is focused solely on efficiency.

In most auctions conducted in the UK, an efficient assignment appears likely to have been achieved. The one example where this may not be true was the award of 2.6GHz spectrum (in a combinatorial clock auction (CCA) alongside 800MHz) in 2013. With hindsight, the outcome of the 2.6GHz assignment appears likely not to have maximised efficiency, although we do not seek to imply that this was due to the *wrong* choice of auction format/rules. Rather, a combination of factors was likely at play, including:

- a complex approach to defining spectrum floors to safeguard competition
- a relatively nascent long-term evolution (LTE) TDD ecosystem (that may have been perceived differently by different bidders in the 2.6GHz auction)
- market entry by BT (which subsequently acquired EE, which as it happened was the largest winner of 2.6GHz spectrum in the auction)[133]
- budgetary constraints for some bidders limiting the level of bids.

In our view, the last of these points may have been especially significant. In particular, an auction outcome in which O2 failed to win any 2.6GHz spectrum was *a priori* unlikely to reflect valuations (and hence represent the most efficient assignment). An apparent budget constraint, combined with a strong desire to secure 800MHz spectrum seem to have been major factors driving this outcome, which it could be argued was inefficient (i.e. O2 might have preferred to have bought 2.6GHz spectrum at the final prices). It then took some years before the BTEE/VMO2 spectrum trade took place, in which BTEE sold to VMO2 some of the 2.6GHz spectrum it had acquired in that auction (but had not fully deployed). Hence, this transaction (i.e. BTEE's sale of spectrum to VMO2) has the potential to create more-efficient spectrum use, since it has avoided BTEE holding licences for spectrum that it does not need, and may have created an incentive for VMO2 to deploy it.

Reserve prices

If efficiency is the primary objective in licensing spectrum, then setting reserve prices at a low value is likely to be the most appropriate choice. This allows for price discovery among bidders and a price for spectrum that is determined by competitive bidding. Whilst there are some arguments to suggest reserve prices can be set too low (e.g. encouraging frivolous bidding or strategic demand reduction that may itself result in an inefficient outcome), it is clearly desirable to avoid reserve prices that themselves influence the auction outcome.

133 In our view, synergies in 2.6GHz ownership were not likely to have been a key driver of BT's acquisition of EE.

In general, Ofcom has adhered to these principles, although the 800MHz reserve price was a fairly high percentage of the final prices, and final prices in the 700MHz auction completed in 2021 were barely above reserve price level.[134]

Artificial scarcity / reserving spectrum

In order to promote an efficient outcome, it is generally recognised that it is important to provide market participants with as clear a view as possible on the future availability of spectrum. Moreover, including all of the available spectrum within the auction process, rather than setting some of it aside for a pre-determined purpose, is likely to promote efficiency.

In Germany, 100MHz of the 3.4–3.8GHz range was set aside for private mobile network use, which limited the availability of this spectrum to public MNOs. This approach was highly contentious, and it is not clear that it will lead to a more-efficient outcome downstream in the German market, given that the private network use is likely to be highly localised and could have been provisioned in other spectrum (for example, 3.8–4.2GHz), thus avoiding setting spectrum aside from this band. This being said, as higher-frequency spectrum starts to be made available for mobile services, it is unclear that nationwide licensing (which is likely to preclude those looking to use spectrum for (relatively) small-scale (individual) private networks) is optimal. We return to this point later in the section.

In the UK, 3.4–3.6GHz and 3.6GHz–3.8GHz spectrum was licensed in two separate auctions, held three years apart. Whilst there were reasons for this approach, it resulted in two auctions which produced materially different prices for technically equivalent spectrum. This could be because at the time of the first auction (for 3.4–3.6GHz spectrum in 2018) the future availability of 3.6–3.8GHz spectrum was not fully clear and so prices were inflated by this (arguably) artificial scarcity. In other words, prices were higher in the first auction as a result of each MNO requiring at least some 3.4–3.6GHz spectrum in order to launch 5G services in a timely manner, and the total amount available not resulting in any excess supply (given the minimum bandwidth that was likely to be economic to deploy). A related reason could have been due to equipment supply, as a wider choice of equipment was available which was designed to operate in 3.4–3.6GHz rather than 3.6–3.8GHz spectrum.

Coverage and QoS obligations

Incorporating coverage (or quality of service, QoS) obligations into auctions is an approach that many regulators use to achieve their policy objectives (for example, improving overall coverage/quality for consumers, or reducing the digital divide). Coverage obligations were incorporated into both the 3G and 4G auctions in the UK (see Section 3.2.7 for details). Coverage obligations were also initially proposed by Ofcom for the 700MHz auction (which took place in 2021), but 700MHz coverage obligations were removed in favour of the commitments that MNOs made to the SRN – a joint

134 Based on initial proposals by Ofcom that also included coverage obligations, the combination of reserve prices and the expected cost of proposed coverage obligations would have been substantially above final auction prices. Our view is that this would have presented a serious risk of an inefficient outcome.

voluntary commitment to network investment in rural areas between the MNOs and government (see Section 3.2.7 for details).[135]

For nationally licensed spectrum, we consider that it may still be appropriate to consider incorporating coverage and/or QoS obligations into auctions. Coverage obligations are likely to be most appropriate at lower frequencies, which are suited to providing wide-area coverage. In mid-band frequencies, which are less suited to providing wide-area coverage and more suited to providing additional capacity, QoS targets may be more suitable (or at least, careful consideration should be given to QoS-based alternatives to coverage obligations). At higher frequencies (e.g. mmWave), where propagation characteristics are weaker, licences are less likely to be made available on a nationwide basis (as discussed in the following subsection), and coverage/QoS obligations are less likely to be suitable.

However the definition of any obligations must be undertaken with due care and attention, since there is a risk of distorting efficient outcomes (e.g. biasing the auction outcome in favour of the party that can deliver the coverage obligation most efficiently).[136] In theory, a better system would be for the auction to focus purely on efficiency (with competition safeguards), but with part of the revenue raised reserved for subsidising network roll-outs through a separate mechanism. Some innovative two-stage auction formats can approximate this, as have been used for example in Denmark and Austria (described below).

Case study: coverage obligations in spectrum auctions in Denmark

The Danish NRA has historically included coverage obligations in spectrum licences awarded by auction.

The 2012 800MHz auction used an innovative approach for incorporating coverage requirements within the CCA format.[137] Operators first bid on packages of lots of available spectrum. The bids in this first round included an obligation to provide average download speeds of 10Mbit/s across 207 postcode areas (divided into three regions).[138] In the next stage, operators were able to bid for regional coverage exemptions in each of the three regions. The auction was configured so that the number of exemptions available was one less than the number of spectrum winners, and so guaranteed the coverage requirement would be assigned to an MNO. There were three bidders in the auction and two winners; TT-Network (a joint venture of Telia and Telenor) won exemptions in all regions in the second round. The prices paid in the auction were some of the lowest in Europe.[139]

135 See paragraph A2.17 and following, https://www.ofcom.org.uk/__data/assets/pdf_file/0021/205554/statement-final-regulations-700mhz-3.6-3.8ghz-spectrum-award.pdf

136 In this context an obligation to increase coverage by a certain amount, rather than an absolute coverage obligation, could be considered.

137 https://www.dotecon.com/publications/digital-dividend-the-danish-way/

138 800MHz auction Information Memorandum; the obligation did not require use of the 800MHz band spectrum.

139 https://www.dotecon.com/assets/images/LA_SMC_2014.pdf

This auction format offers an alternative to imposing an obligation on all licensees, and a way of separating coverage requirements from the initial bids for spectrum.

Similar approaches have been followed in subsequent auctions in Denmark. For example, in the most recent (combinatorial) spectrum auction in 2021, obligations were attached to the 3.4–3.8GHz licences to achieve 60% population coverage by the end of 2023, and 75% by the end of 2025. The 2100MHz licences also incorporated coverage requirements for poorly covered areas, and a separate second auction stage was included in which MNOs could place an additional bid to specify one of three coverage zones (of similar size, each containing 40/41 target areas).[140]

Case study: coverage obligations in spectrum auctions in Austria

The 2020 combinatorial spectrum auction in Austria consisted of four stages. The first two stages took the form of a simultaneous multiple round ascending auction (SMRA) to assign lots first in the 700MHz and 2100MHz bands, and then in the 1400MHz band. Each 700MHz lot included a minimum coverage obligation. In the third stage, MNOs submitted sealed bids to secure specific frequencies within the three bands. In the fourth and final stage, MNOs submitted sealed bids to accept extended coverage obligations in exchange for a price reduction. The extended coverage obligations assigned in stage four were not bound to any specific frequencies.[141]

We note that the incorporation of coverage obligations in UK auctions may be less of a concern in future, as a move to higher frequencies for new spectrum bands is underway. However, coverage considerations are likely to be associated with any new award of sub-1GHz spectrum (e.g. in the 600MHz band).

Geographical extent of licences (national or sub-national)

Wide-area licences can be awarded on a national or sub-national (regional) basis. All mobile spectrum licences auctioned to date in the UK (i.e. the 3.6GHz band and below) have been nationwide. As discussed in Section 3.2.3, Ofcom has conducted auctions of regional licences for non-mobile spectrum, and these licences have subsequently been consolidated, and the usage changed, to enable mobile use (e.g. spectrum within the 3.4–3.8GHz band, which was originally auctioned for FWA use on a regional basis).

Where MNOs operate a nationwide network (which the four UK MNOs do), the extent to which they will deploy a given frequency band across their network will depend on the frequency of the band in question and the distribution of traffic across the operators' networks:

- **At 'lower' frequencies (e.g. sub-1GHz)** operators are likely to have demand to deploy spectrum in most locations across their entire network to provide widespread outdoor coverage,

140 https://ens.dk/sites/ens.dk/files/Tele/information_memorandum_1.pdf

141 https://www.rtr.at/TKP/was_wir_tun/telekommunikation/spectrum/TenderDocument-700_1500_2100_MHz-F_1_16_EN-non-binding-trans.pdf

and indoor coverage. In this case, there is a strong case for licences to be offered on a nationwide basis.

- **In mid-band frequencies (e.g. 2.3GHz, 2.6GHz, 3.5GHz)** it may or may not be necessary or commercially viable for the MNOs to deploy spectrum across their entire network. Since these bands are most suitable for adding capacity, the lower user density in rural areas might mean there is less demand to deploy these frequencies outside of urban areas (this assumes traffic per subscriber remains similar between rural and urban users – in a situation where frequencies are being used for a different purpose (for example, 4G or 5G-based FWA in a rural area), there might be demand for deployment in specific rural locations).

- **At 'higher' frequencies (e.g. mmWave)**, where propagation characteristics are weaker, demand/deployments will in all likelihood be confined to more localised areas In these bands there is clearer rationale for regional or sub-regional licences to be offered. This is discussed in Section 5.2.3.

In certain 'medium' frequency bands, there has been more-limited geographical deployment (i.e. lower geographical spectrum utilisation) in the UK to date. For example, none of the UK MNOs has deployed 2.6GHz or 3.4–3.8GHz bands across its entire site grid. As a result, it could be argued that there is room for geographical spectrum utilisation to be increased. There might also be risk of a growing mobile digital divide, with data speeds in urban areas increasing much more rapidly than in rural areas.

The question arises as to whether a sub-national licensing approach would have been better for mobile spectrum at 3.6GHz and below. Our view is that there is not good evidence to suggest that this is the case:

- **It is not clear that a regional licensing approach would have produced a better outcome. Indeed, there are good reasons to think it may have produced a worse outcome**, not least because of complexities inherent in specifying optimal regional licence areas and the risk that MNOs may not have been able to secure spectrum in all areas where they have demand. Where spectrum cannot be secured in particular areas by an MNO, this not only means the MNO cannot invest in those areas, but may also jeopardise investment in other areas, given the economies of scale needed for investments to be made. We note that Ofcom auctioned the 28GHz band (for FWA) on a regional basis in 2000, and several lots went unsold; [142] some seven years later, Ofcom re-auctioned the unsold lots alongside new nationwide lots.[143] Through licence trading

142 The Radiocommunications Agency (RA) auctioned broadband fixed wireless access (BFWA) licences in the 28GHz band in November 2000. It offered 42 licences (3 in each of 14 regions) and sold 16 of them (including licences in each region), with bids close to reserve prices. All licences were for 2×112MHz. Over 55% of the UK was covered by the licences bought. See http://webarchive.nationalarchives.gov.uk/20080710151952/http://www.ofcom.org.uk/static/archive/spectrumauctions/bfwa/bfwa_index.htm

143 Unsold lots in the 28GHz band were auctioned in 2007, alongside the 10GHz, 32GHz and 40GHz bands. Two new nationwide 2×112MHz lots were also auctioned in the 28GHz band. See https://webarchive.nationalarchives.gov.uk/ukgwa/20220104120108/https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive/1040award

and market consolidation, the regionally auctioned licences are now largely owned by Three, Vodafone and VMO2. These MNOs typically own the same spectrum block across several regions (or indeed all regions).

- **The UK's approach of using nationwide licences for mobile spectrum aligns with precedents in other European markets**. Nearly all European auctions have used nationwide licences, with only limited exceptions (Austria and Ireland in the 3.4–3.8GHz band,[144] and Spain and Norway in the 2.6GHz band[145]). A handful of non-European markets do generally auction mobile spectrum on a regional basis, though these tend to be geographically extremely large or have very high populations (and as such, may have historically supported regional mobile operators in a way which the UK has not): for example, Australia, Brazil, Canada, India and the USA.

- **MNOs have stated that nationwide mid-band licences are needed for 5G to be a success**. In June 2022, the GSMA published a public policy 'position' paper on 5G spectrum issues, highlighting the areas where governments, regulators and the mobile industry must co-operate to make 5G a success. Position number four states that "exclusively licensed spectrum over wide geographical areas is vital to the success of 5G". In particular, "5G services benefit from significant amounts of exclusively licensed spectrum that cover entire countries. Nationwide mobile spectrum licences continue to be important, including in mid-bands".

- Finally, (as described in Section 3.2.4), **we note that the introduction of LALs has facilitated access to spectrum (by non-MNO players) in geographical areas where it is underutilised by MNOs** (thus facilitating greater geographical utilisation going forward). As of April 2022, Ofcom had issued 27 LALs: 21 in the 2.6GHz band, 3 in the 1800MHz band and 3 in the 3.4–3.8GHz band.

5.2.2 Optimal solution for reassigning spectrum upon expiry

Options for reassigning spectrum

Several options are available for reassigning spectrum upon licence expiry, which can be broadly categorised as follows:

- **Automatic renewal**, whereby the current licence holder retains the spectrum licence. This can come about through the issuance of indefinite licences, or where there is an implicit high expectation of renewal. The UK approach of an initial term followed by an indefinite licence subject to ALFs falls into this category.

144 We understand that particular circumstances led to a regional licensing approach being used in these cases. Namely, FWA operators were using spectrum in the band and needed the opportunity to acquire spectrum to continue to offer those services. In both Austria and Ireland, the MNOs ended up winning large contiguous blocks across all regions (i.e. effectively winning nationwide licences). We also note that various countries have reserved a portion of the 3.5GHz band for non-MNO players, which has in some cases been auctioned on a regional basis (e.g. Croatia).

145 In Norway, 2.6GHz licences (with a 15-year duration) were auctioned on a regional basis in 2007. However, upon expiry the 2.6GHz band was re-auctioned on a national basis in 2021.

- **Administrative reassignment to another operator or administrative/negotiated renewal** (e.g. where the existing licence holder is offered renewal in exchange for accepting certain licence conditions, such as investment or coverage obligations).

- **Auction-based approaches**, whereby the spectrum is re-auctioned and either the current licence holder or another operator can obtain the licence. As well as full auctions of all expiring spectrum licences (with or without prior harmonisation of the expiry dates of licences), hybrid approaches can be used whereby part of the available spectrum has licences automatically renewed and the remaining part is auctioned, or where a licence holder retains a first right of purchase.

Below we describe the approach to relicensing and licence duration currently used in the UK (for mobile spectrum assigned on a national basis), and compare this to alternative approaches used in other markets.

► ***Indefinite duration, with ALFs applying after an initial term***

In the UK, Ofcom's standard approach is to auction nationwide mobile spectrum licences with an indefinite duration but an initial term of 20 years, after which ALFs apply.[146] This is unusual: we are not aware of any other countries where this exact approach is used (although there are very similar approaches in some other markets, e.g. Canada, as discussed below).

As discussed in Section 3.2.5, Ofcom has consulted on auctioning wide-area (city/town-wide) licences in the 26GHz band in high-density areas. This is also one of the approaches considered for the 40GHz band. In its consultation, Ofcom invited stakeholder input on the duration of licences, and proposed a fixed term of between 10 and 15 years. Other possible options consulted upon included fixed-term licences with a different duration (e.g. 5 or 20 years), or indefinite licences with an initial term of between 5 and 15 years, after which ALFs would apply.[147]

Case study: Canada

In Canada, licences are issued by auction with an initial term of up to 20 years, with a high expectation of renewal for subsequent terms. A licence may not be renewed if the licence conditions are breached, or if the spectrum is to be allocated to a new service. Two years prior to the end of the licence term for a specific band, a consultation will be held to set licence conditions and fees which "*reflect some measure of market value*". Renewed licences are subject to annual licence renewal fees, adjusted for the consumer price index (CPI).[148] Total or partial transfers of licences are allowed.[149]

146 As described in Section 3.2.4, Shared Access Licences are made available on an indefinite basis, with ALFs that are (currently) cost based. Local Access Licences have a default duration of three years (for a one-off GBP950 fee), with longer licences possible with the support of the incumbent licensee.

147 Section 10, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/237258/mmwave-spectrum-condoc.pdf

148 https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf01713.html

149 Sections 3.5 to 3.7, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01626.html#section35

► ***Indefinite duration***

Licences with indefinite duration (or a high expectation of renewal) are relatively uncommon, but the USA is a notable exception, as described below.

Case study: USA[150]

In the USA, mobile spectrum licences have an initial term, but with a high expectation of renewal (and can therefore be considered indefinite).

In 2017, the USA adopted a standardised renewal framework for most wireless radio services licences, both geographical (i.e. licences which permit use over a wide area) and site-based (i.e. licences which permit transmission from a single defined set of base stations). The Federal Communications Commission's (FCC's) stated motivations were to promote efficient use of spectrum and to afford licence holders more certainty with regard to licence duration and renewal requirements. This new framework aligned other spectrum licences with the framework already established for mobile licences in the 700MHz and 600MHz bands (auctioned in 2008 and 2016 respectively).

Following a spectrum auction, licences are awarded with an initial licence term (typically ten years), at the end of which the licensee must submit a renewal application if it wishes to continue to hold the licence. To be granted renewal, the licensee must demonstrate compliance with any licence-specific rules to construct and continuously provide a required level of service. At subsequent renewals the licensee must demonstrate continued provision of the required level of service. The renewal framework is such that no competing renewal applications are permitted. If a renewal application is denied, then the spectrum in question is returned to the FCC for reassignment.

Licensees that are also subject to a 'performance requirement' (e.g. a coverage obligation to be met by the end of the initial term) must also demonstrate that they fulfil the necessary requirements in order to be granted renewal.

► ***Definite duration, after which spectrum is re-auctioned***

Licence durations of 15 or 20 years are common. In EU Member States, a European Commission (EC) directive requires a minimum mobile licence duration of 15 years (with a 5-year extension).

Indefinite licences are less common, with many markets (including the majority of European markets) re-auctioning licences after a definite term. A recent example is the re-auctioning of 900MHz, 1800MHz and 2100MHz spectrum in Belgium.

150 https://www.fcc.gov/document/fcc-reforms-license-renewal-rules-wireless-spectrum-0, https://www.federalregister.gov/documents/2017/09/01/2017-18501/uniform-license-renewal-discontinuance-of-operation-and-geographic-partitioning-and-spectrum

Case study: EC's Electronic Communications Code

Article 49 of the European Commission's recent Electronic Communications Code (ECC) aims to facilitate 5G deployment by providing investment predictability through minimum spectrum licence durations.[151]

NRAs in Member States must award mobile licences with a minimum initial term of 15 years and put in place provisions to extend licence duration to at least 20 years. At least two years prior to the end of the initial term, NRAs must assess certain criteria (e.g. efficient use of spectrum, general-interest objectives and undistorted competition) and grant an extension where the criteria are fulfilled. Other interested parties are invited to provide comments during the assessment.[152] The EC originally proposed 25-year minimum licences (as argued for by stakeholders in the mobile industry), but this was reduced to 20 years.

There have been recent examples of markets increasing licence durations significantly (e.g. to 40 years in Spain, as described below).

Case study: Spain[153]

In April 2021, Spain increased the maximum spectrum licence duration from 20 years to 40 years.[154] Following the change in legislation, the 700MHz auction took place in July 2021 and licences were issued with a 20-year initial term, followed by automatic renewal for an additional 20-year period. Before the end of the initial term, the NRA will evaluate whether the licensee has demonstrated compliance with the licence conditions (e.g. coverage objectives and commitment to technological development) and other interested parties are able to submit comments. The 20-year extension will be granted on the basis of this review.

- ***Definite duration, after which spectrum is offered for renewal in exchange for certain commitments***

There have been handful of examples of this approach in European markets in recent years, including Portugal and France (described below).

Case study: Portugal

In 2021, the Autoridade Nacional de Comunicações in Portugal (ANACOM) agreed to renew MEO and Vodafone licences in the 900MHz and 1800MHz bands in exchange for the MNOs meeting additional coverage obligations. The licences were renewed until 2033, by which time the MNOs are obliged to cover an additional 100 areas with low population density which fall outside the scope

151 https://www.europarl.europa.eu/legislative-train/carriage/jd-electronic-communications-code/report?sid=6001

152 Article 49, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L1972

153 https://portal.mineco.gob.es/es-es/comunicacion/Paginas/210721_np_-subasta_.aspx, https://boe.es/boe/dias/2021/05/31/pdfs/BOE-A-2021-9060.pdf

154 https://portal.mineco.gob.es/es-es/comunicacion/Paginas/210427_np_frecuencias.aspx

of the existing 5G obligations. Coverage in these areas must extend to 90% of the population and sustain a minimum speed of 100Mbit/s.[155]

Case study: France

An agreement was made in 2018 between the government, the NRA and French MNOs that instead of re-auctioning 900MHz, 1800MHz and 2100MHz licences upon their expiry (between 2021 and 2024), Autorité de Régulation des Communications Electroniques et des Postes (ARCEP) would renew the licences, with new coverage obligations incorporated. The obligations aim to accelerate the improvement of coverage and quality nationwide, with a particular focus on rural areas. Each MNO is to deploy at least 5000 new cell sites nationwide (some shared) and all cell sites are to be upgraded to 4G. Total indoor coverage is to be achieved by offering voice-over-Wi-Fi solutions, and the pace of 4G coverage of transport corridors is to be accelerated (only applicable to 1800MHz licensees).[156]

The licences were renewed for ten years with no up-front cost, and the previous annual fees are still applicable (1% of revenue generated by use of the band plus a small per-MHz fee). Annual fees will stay flat over the period.[157]

Trade-offs among the different options

When considering the different options, regulators need to consider the trade-offs among the following objectives:

- market competitiveness and efficiency
- investment-friendliness and service continuity
- spectrum manageability
- the transparency and fairness of award.

Each of the relicensing approaches will have different advantages and disadvantages with respect to these trade-offs and their specific policy objectives.

- **Automatic renewal** regimes are investment-friendly, but result in low levels of spectrum manageability. In addition, as with administrative reassignment, complicated issues such as how much to charge for the spectrum may arise (which can be compared with the debates around how Ofcom sets ALFs, as discussed in Section 5.3).

- **Administrative reassignment** procedures allow for maximum spectrum manageability and can be pro-competitive, but are prone to regulatory failure. In particular, this manageability may be achieved at the cost of decreased investment incentives and minimal transparency.

155 https://www.anacom.pt/render.jsp?contentId=1623481, https://www.anacom.pt/render.jsp?contentId=1725815

156 https://en.arcep.fr/news/press-releases/view/n/new-deal-for-mobile-2.html

157 Articles 13-2-2 and 13-3, https://www.legifrance.gouv.fr/loda/id/LEGIARTI000037447798/2018-10-01/

- **Auction-based approaches** ensure high levels of competition and are generally transparent and fair. However, the uncertainty they introduce for operators is likely to dampen investment incentives, while manageability and potentially service continuity are also reduced.

Overall, our view is that the approach followed by Ofcom strikes a good balance in terms of achieving the objectives listed above. Re-auctioning spectrum, as is common in many European markets, creates a range of potential issues that are, in our view, likely to outweigh the benefits. The approach followed by Ofcom creates a more investment-friendly environment than with a re-auctioning approach.

Automatic renewal approaches, whereby licences are effectively indefinite, as in the USA, have some merit and we consider them as an alternative option in our recommendations (see Section 6.1.3). However, it is important to note that:

- Under truly perpetual licences, it is possible that auction prices would increase – we note for example that auction prices for mobile spectrum in the USA are generally significantly higher than in the UK. If this were to transpire, it could be a worse outcome than under the current approach (e.g. MNOs may incur a similar present value (PV) of costs for their spectrum licences, but would pay all of this up front (or at least earlier than under the current approach)).

- Alternatively, auction prices may not go up materially, meaning MNOs simply pay less for the use of the spectrum. It is arguable that this does not provide value for money for the taxpayer or maximise social benefits from use of a scarce public asset (another objective of the Cave report).

Administrative renewal approaches (or a suitable variant thereof), such as used in France, are an alternative that could be worth considering in the UK. Under such an approach, an extension to an initial 20-year licence term could be offered in exchange for a coverage or investment commitment from the MNO, rather than a 'cash' ALF. We discuss considerations related to this further in Section 6.1.3.

Related to the issue of how spectrum licences are reassigned upon expiry is the question of licence duration. Longer licence durations reduce the frequency with which relicensing must be organised; where licences are indefinite, no reassignment mechanism is required (which can be considered as automatic renewal at zero cost).

Longer licence durations offer greater certainty, creating a positive environment for investment. Where MNOs have a spectrum licence of fixed duration with no expectation/guarantee of renewal, the case for network investment (which depends on use of the spectrum) diminishes as the expiry date approaches. At some point (potentially several years) prior to expiry, the MNO may not consider there to be any business case for further investment. On the other hand, there can be competition issues associated with longer licence durations, since new entrants do not have the opportunity to acquire the spectrum until licence expiry (except via trading).

5.2.3 Mobile spectrum assignment in higher frequencies

As previously described in Section 5.2.1, as mobile network deployments start to use higher frequency bands with inferior propagation characteristics for wide-area coverage, shared/local access licensing is likely to become a more appropriate mechanism for awarding spectrum. The greater bandwidth availability in higher bands might also mean that demand is generally unlikely to exceed supply in many locations (although it is noted that the need for wider contiguous bandwidths in higher bands might increase demand).

Our view is that auctions will remains suitable for lower bands (used primarily to provide coverage) in future. For higher bands (such as mmWave bands, which are used primarily to provide capacity), Ofcom is already moving towards a hybrid approach for spectrum assignment for the 26GHz band. If moving to higher frequencies results in a concentration of mobile spectrum demand within urban areas only, a potential upside could be the increased sharing possibilities that would arise between mobile use in urban locations and other uses in non-urban locations. These sharing possibilities would be dependent on the nature of existing uses, and will continue to require case-by-case consideration.

5.3 Pricing (ALFs)

5.3.1 Context for annual licence fees applied to mobile spectrum

Revision of approach for calculating ALFs

The Wireless Telegraphy Act 1998 (WT Act) facilitated the use of market mechanisms for spectrum management for the first time in the UK. Under the WT Act, AIP for spectrum used by public mobile networks was implemented in step changes from 1998 to 2002.

The original approach used for calculating AIP (which was in place at the time of the Cave report) was based on a model devised by consultants NERA and Smith Systems in 1996, which calculated the opportunity cost to existing users of the band.[158] In agreement with the government, AIP was initially rolled out by setting fees at 50% of the levels recommended by NERA and Smith Systems.

In December 2010, Ofcom published its Strategic Review of Spectrum Pricing (SRSP), which outlined updated principles for setting AIP.[159] The same month, a government Direction was issued which required Ofcom to (among other things) revise the 900/1800MHz ALFs and set 2100MHz ALFs to "reflect full market value".[160] Ofcom states that "*the purpose of AIP is to set fees for*

158 The opportunity cost was taken to be the cost of the least-cost alternative (LCA) to using spectrum that would enable the same output to be produced.

159 https://www.ofcom.org.uk/__data/assets/pdf_file/0024/42909/srsp-statement.pdf

160 https://www.legislation.gov.uk/uksi/2010/3024/article/6/made

spectrum holdings that reflect the market value of the spectrum (based on its opportunity cost)[161] *in order to promote the optimal use of spectrum, in line with our duties*".[162]

Following the government Direction, Ofcom has now set updated ALFs for the 900MHz and 1800MHz bands at a level which it considers represents the full market value of these bands in mobile use. Full market value is estimated based on prices paid at auctions (in the UK as well as internationally) for comparable mobile spectrum. Ofcom states that it adopts a conservative approach when interpreting the evidence of auction benchmarks to estimate full market value, given the asymmetry of risk associated with setting fees too high as opposed to too low.[163] 2100MHz licences have now reached the end of their initial term, and Ofcom has set ALFs for these licences using the same approach as for 900MHz and 1800MHz bands; ALFs also apply to certain spectrum in the 3.5GHz band. Further details are provided below.

ALFs applicable in different mobile bands

► *900MHz and 1800MHz*[164]

The 900MHz and 1800MHz bands were assigned for public mobile use before 2000, with licences awarded via comparative selection (i.e. a 'beauty contest'); see Section 3.2.3. As a consequence, up-front payments similar to auction payments have not been made for licences in these bands, and ALFs have applied since these bands were first used for mobile communications. However, the approach for calculating ALFs has been revised several times since the bands were first assigned, notably with the introduction of AIP-based fees in the early 2000s, as discussed above.

The 2002 level for the 900MHz and 1800MHz bands, shown in Figure 5.2 below, was set under the NERA–Smith approach (explained above).

Figure 5.2: Final ALFs for 900 and 1800MHz (2002) [Source: Ofcom,[165] *2022]*

Decision	900MHz band fee (GBP million / MHz / annum)	1800MHz band fee (GBP million / MHz / annum)
2002 licence charges regulations	0.3564	0.2772

161 Ofcom defines 'market value' to be the market-clearing price in a well-functioning market, or the forward-looking marginal opportunity cost of the spectrum. 'Opportunity cost' is defined to mean the value to the next highest value use or user that is denied access to the spectrum.

162 https://www.ofcom.org.uk/__data/assets/pdf_file/0027/229428/1900_2100-mhz-statement.pdf. Paragraph 3.33 of the SRSP states that: "*the purpose of AIP is to provide users with a sustained long-term signal of the value of the spectrum as indicated by its opportunity cost in the next highest use and, as a result, to give them incentives to use it in a way that maximises benefits for society over time*".

163 The risk is greater if fees are set too high, as in this case there is a risk that spectrum may be returned to the regulator.

164 https://www.ofcom.org.uk/consultations-and-statements/category-2/annual-licence-fees-further-consultation

165 https://www.legislation.gov.uk/uksi/2002/1700/schedule/2/made

The government Direction of 2010 required Ofcom to revise the 900/1800MHz ALFs to reflect full market value, taking into account the prices paid in the (at the time) forthcoming 4G auction (for 800MHz and 2.6GHz) when setting ALFs.[166] The 4G auction was completed in March 2013, and Ofcom held a consultation on revised 900/1800MHz ALFs later that year. Several further proposals were consulted on before fees were finalised in September 2015 at the levels shown in Figure 5.3 below.

As the 900MHz and 1800MHz bands had not been auctioned in the UK, Ofcom used other recent UK and international auctions to calculate ALFs. Specifically, Ofcom relied on the UK's March 2013 auction of 800MHz and 2.6GHz bands, alongside benchmarks of auction prices for 800MHz, 900MHz, 1800MHz and 2.6GHz bands in other European countries since 2010.[167] The UK 900MHz valuation was derived from its value relative to 800MHz, while the UK 1800MHz valuation was derived from its relative position between the value of 800MHz and 2.6GHz spectrum.[168]

Figure 5.3: Final ALFs for 900 and 1800MHz (2015) [Source: Ofcom,[168] 2022]

Decision	900MHz band fee (GBP million / MHz / annum in March 2013 prices)	1800MHz band fee (GBP million / MHz / annum in March 2013 prices)
September 2015 statement	1.128	0.815

Some UK MNOs took legal action against Ofcom's ALF determination of September 2015. When their appeal was upheld in November 2017, Ofcom's 2015 ALF decision was deemed invalid, on the basis that Ofcom had not sufficiently fulfilled its statutory duties (in particular its duty to carry out an impact assessment under Section 7 of the Communications Act, to ensure that ALFs would not adversely affect competition and would promote the efficient use of spectrum). As a result, ALFs temporarily reverted to the 2002 values.[169]

In 2018, Ofcom concluded its reassessment of ALFs for the 900MHz and 1800MHz bands. As shown in Figure 5.4 below, its 2018 ALF decision represented only a slight reduction compared to the 2015 ALF decision.

Figure 5.4: Final ALFs for 900 and 1800MHz (2018) [Source: Ofcom,[169] 2022]

Decision	900MHz band fee (GBP million / MHz / annum in April 2018 prices)	1800MHz band fee (GBP million / MHz / annum in April 2018 prices)
December 2018 statement	1.093	0.805

166 Paragraphs 3.7–3.10; https://www.ofcom.org.uk/__data/assets/pdf_file/0023/57326/900-1800-fees.pdf

167 Available benchmark countries were categorised in three tiers according to their similarity to UK market values.

168 https://www.ofcom.org.uk/__data/assets/pdf_file/0033/79764/statement.pdf

169 https://www.ofcom.org.uk/__data/assets/pdf_file/0020/130547/Statement-Annual-licence-fees-900-MHz-and-1800-MHz.pdf

Further litigation followed concerning the rebate due to MNOs. In February 2020, the court ruled in favour of refunding the difference between what the MNOs had paid between 2015 and 2018 with the pre-2015 fees (as opposed to the 2018 fees), which meant the MNOs were entitled to a total rebate of around GBP220 million.[170]

► *UKB/Three spectrum in the 3.4–3.6GHz bands*

As discussed in Section 3.2.3 earlier, the 40MHz of spectrum licensed to UKB (owned by MNO Three) in the 3.4GHz band was assigned via auction in 2003. In 2014, Ofcom granted a variation to this licence to be of indefinite duration, with ALFs due from July 2018 following expiry of the initial term.[171] The 80MHz of spectrum licensed to Three in the 3.6GHz band was assigned administratively, and ALFs were payable for many years. Prior to the recent revision of ALFs discussed below, fees for this spectrum were set out in the Wireless Telegraphy (Licence Charges) Regulations 2011.

In June 2019, Ofcom announced its decision to set new ALFs for the 40MHz of 3.4GHz spectrum and the 80MHz of 3.6GHz spectrum licensed to Three.[172] The decision set the fees for both bands at GBP0.435 million per MHz per annum (in April 2018 prices) based on the results of the 3.4GHz auction (in April 2018). The new ALFs applied to the 3.4GHz spectrum from the end of July 2019. Meanwhile, a phased approach was used for 3.6GHz spectrum, with Three paying 50% of the difference between the 2011 and 2019 fees until the end of June 2020.

As discussed in Section 5.3.5 later, in order to help reduce barriers to trading, in October 2022 Ofcom decided to align UKB's licence terms with those of other licences in the 3.4–3.8GHz band. This involved requiring UKB to 'pay off' the future ALFs due on its 3.4GHz and 3.6GHz licences (to 2038 or 2041) through a single lump sum of equivalent value for each band. Notably, the calculation of each lump-sum amount is based on the relevant auction price. That is, the 3.4GHz auction price is used to calculate the lump-sum value for 3.4GHz ALFs, and the 3.6GHz auction price (which was considerably lower) is used to calculate the value for 3.6GHz ALFs (with any ALF payments that have already been made being netted off the lump-sum amount).

► *2100MHz*

The initial 20-year term for the 2100MHz 3G licences expired in 2021, and ALFs apply from 2022 onwards.

Unlike with the 3.4–3.6GHz bands, Ofcom had no relevant recent UK auctions to refer to when calculating ALFs for 2100MHz spectrum (the 2100MHz auction had taken place in 2000 and Ofcom decided that it was too outdated to inform current valuations). Ofcom therefore applied the same approach for calculating ALFs as was used for the 900MHz and 1800MHz bands, combining the

170 https://www.judiciary.uk/wp-content/uploads/2020/02/Vodafone-APPROVED-JUDGMENT.pdf

171 https://www.ofcom.org.uk/consultations-and-statements/category-2/uk-broadband-licence

172 https://www.ofcom.org.uk/__data/assets/pdf_file/0013/151231/statement-annual-licence-fees-uk-3.4-ghz-and-3.6-ghz-spectrum.pdf

three latest UK auction results[173] with international benchmarks of the relative values of the different spectrum bands.[174]

In December 2021, Ofcom announced its decision to set new base ALF levels at GBP0.561 million per MHz per annum for paired 2100MHz spectrum (in April 2021 prices).[174]

Summary of ALFs due in 2022

Figure 5.5 below shows the ALFs to be paid for 2022 per MNO and per band.

Figure 5.5: Summary of ALFs (GBP million in 2022 terms) due from MNOs in 2022 [Source: Ofcom, ONS,[175] Analysys Mason, 2022]

MNO	Spectrum (MHz)					ALF due in 2022 (GBP million)					Total ALF
	900MHz	1800MHz	2100MHz	3.4GHz	3.6GHz	900MHz	1800MHz	2100MHz	3.4GHz	3.6GHz	
BTEE	-	90.0	40.0	-	-	-	85	25	-	-	**110**
Vodafone	34.8	11.6	29.6	-	-	45	11	19	-	-	**74**
VMO2	34.8	11.6	20.0	-	-	45	11	13	-	-	**68**
Three	-	30.0	29.5	40.0	80.0	-	28	19	20	40	**107**
Total ALF						**89**	**135**	**75**	**20**	**40**	**360**

All other national mobile spectrum is currently within its initial term. However, ALFs will be due for the 1400MHz licences following the end of their initial 15-year term in May 2023.

In summary, ALFs for currently assigned mobile spectrum are being set to reflect what Ofcom considers is the full mobile market value, and they currently total over GBP330 million per year across all MNOs (with further increases on the horizon when ALFs become due on newer bands, e.g. 1400MHz). Given the existence of spectrum trading, wide acknowledgement that mobile is the highest-value use of the bands in question, and the global convergence of mobile technologies that has concentrated public mobile deployment into these bands, the question arises as to whether AIP-based ALFs set at full market value are necessary to incentivise efficient use of spectrum and/or to maximise the benefits of mobile communications to consumers.

173 Auctions of 800MHz and 2.6GHz in March 2013, 2.3GHz and 3.4GHz in April 2018, and 700MHz and 3.6GHz in March 2021.

174 https://www.ofcom.org.uk/__data/assets/pdf_file/0027/229428/1900_2100-mhz-statement.pdf

175 Calculation of 2022 ALFs uses consumer price index (CPI) tables from the Office for National Statistics (ONS); https://www.ons.gov.uk/economy/inflationandpriceindices/datasets/consumerpriceinflation

5.3.2 Are AIP-based ALFs necessary to promote economic efficiency?

ALFs in mobile bands

A key question that we have considered in our analysis is whether ALFs are necessary to promote economic and technical efficiency in mobile bands. MNOs are now clearly the highest-value users of the spectrum that is already available for public mobile use. This calls into question whether ALFs set at full market value are required to promote economic spectrum efficiency or innovation.

The strong industry support for global mobile standards, and strong consumer demand for devices to be connected wherever the user is located (including while travelling) has also made market-driven alternative (proprietary) network technology innovation less feasible. Given the convergence of mobile technologies within 3GPP to effectively one common standard, there are less marked differences in *technical efficiency* of spectrum use between MNOs. Nevertheless, there can still be important differences in *economic efficiency* (i.e. different MNOs can value the same spectrum block differently (in some cases very differently) due to their different market shares, different congestion levels, other spectrum holdings, etc.). As discussed in Section 3.2.1, clear evidence for this can be seen in the substantial differences in the amounts that UK MNOs bid for identical packages in the 800MHz and 2.6GHz auction.

However, with a functioning trading system in place, MNOs have the ability to trade their spectrum licences, and – according to standard economic theory – they therefore face the opportunity cost of their spectrum. If they choose not to trade, then either they are already the most economically efficient user, or there are countervailing strategic reasons (which ALFs are unlikely to override in the context of generally quite similar valuations for spectrum across the MNOs[176]).

The primary[177] counter-argument that Ofcom[178] has made to this position is that while the above may be true according to economic theory, it may not be true in practice: whether or not it is

176 We understand that Ofcom agrees with this point; see footnote 116 of the 900/1800MHz 2018 ALF consultation.

177 A secondary counter-argument is that lack of price information (due to lack of previous mobile trades) means MNOs do not have a good awareness of the opportunity cost of their spectrum, and so it is difficult for them to evaluate the case for trading. This argument was made in Ofcom's 900/1800MHz 2018 decision (see paragraph 5.43), but not in its 2100MHz 2021 decision (see paragraph 5.20 (a)). We do not consider this argument to be compelling. As Ofcom states in both decisions, if MNOs wish to trade their existing spectrum holdings, they can identify potential buyers (e.g. among other MNOs) and assess the value of spectrum through negotiations and/or valuation exercises. More broadly, the argument could be made that there is not a well-functioning trading system (e.g. due to high transaction costs or other co-ordination problems). However, as discussed in Section 5.1, we do not think this is the case.

178 Ofcom has made various counter-arguments to this position in its SRSP and in the course of its mobile ALF consultations and statements, for example:

- Paragraphs 5.8–5.22 of the December 2021 2100MHz ALF decision (https://www.ofcom.org.uk/__data/assets/pdf_file/0027/229428/1900_2100-mhz-statement.pdf)
- Paragraphs 5.36–5.49 of the December 2018 900/1800MHz ALF decision; https://www.ofcom.org.uk/__data/assets/pdf_file/0020/130547/Statement-Annual-licence-fees-900-MHz-and-1800-MHz.pdf

economically rational, in reality MNOs may be more responsive to a direct cost than an opportunity cost (i.e. foregone revenue). Ofcom's 2100MHz 2021 ALF decision (paragraph 5.20 (b)) states that this situation may arise because:

> "*i) Managers making the decisions may lack the incentives to act on opportunity costs of holding spectrum, e.g. if an organisation considers minimising costs a greater priority, and places less weight on realising untapped revenues from existing spectrum holdings; and/or*
>
> *ii) Managers' response to opportunity costs could also depend on whether outcomes are framed in terms of losses or gains; studies have shown that losses tend to carry greater weight than equivalent gains, which would imply that managers may respond more easily to the direct cost of a licence fee than the foregone revenues from trading spectrum.*"

We consider that this reasoning could have some merit. However, in this context we also consider the reasoning to be somewhat conjectural: we are not aware of strong evidence that demonstrates this is how MNOs actually behave.[179]

In further support of its view, Ofcom has noted that some MNOs have claimed that higher ALFs put upward pressure on retail prices and reduce investment, and that this would not be the case if the opportunity cost of foregone revenue was already fully reflected by decision makers. We agree with this logic, but (as discussed in Section 5.3.6), dispute the claim that some MNOs are making in this regard.

Finally, we note that there has not been significantly more trading of mobile licences in spectrum bands where ALFs apply than in spectrum bands where ALFs do not (yet) apply. As explained in Section 5.1.4, we do not consider that the limited volume of trades implies the trading market is not functioning well (or that operators are less responsive to opportunity costs than direct costs). In our view, the limited amount of trading may be a result of other factors, such as:

- The relatively low number of national mobile licences available for trading
- The complexity of permanent trades and the potential existence of strategic incentives for MNOs not to trade to retail competitors
- Auctions generally leading to economically efficient outcomes, such that mobile spectrum is already in the hands of its highest-value users (at least initially following auctions).

- Paragraphs 5.47–5.61 of the June 2018 900/1800MHz ALF consultation; https://www.ofcom.org.uk/__data/assets/pdf_file/0022/114736/consultation-alf.pdf
- Paragraphs A5.15–A5.19 of the August 2014 900/1800MHz ALF consultation; https://www.ofcom.org.uk/__data/assets/pdf_file/0025/74680/condoc.pdf
- Paragraphs 4.189–4.212 of the SRSP; https://www.ofcom.org.uk/__data/assets/pdf_file/0024/42909/srsp-statement.pdf

179 In paragraph 5.45 of the 900/1800MHz 2018 ALF decision, Ofcom states that it has not received any documentary evidence to suggest its view is incorrect, and that it would expect MNOs to be able and incentivised to provide such evidence if it existed. We note, however, that (at least some) MNOs take a different view: for example, Three has stated that Ofcom could determine that MNOs take account of opportunity cost through information gathering.

ALFs in non-mobile bands

For the reasons explained above, we do not consider there to be clear evidence that ALFs are needed to promote the efficient use of mobile spectrum. However, although not within the scope of this report, we note that our reasoning may not be applicable to all other spectrum bands, i.e. commercial spectrum bands for other types of use, as well as public-sector spectrum.

For non-mobile commercial spectrum bands, there may be co-ordination issues associated with achieving efficiency, which could warrant the use of AIP-based ALFs. There may be alternative uses for a commercial spectrum band that are more technically or economically efficient, but the new use cannot be introduced without multiple (or indeed all) incumbent users trading their licences (or moving to the new technology) simultaneously or in a co-ordinated fashion. This situation may arise where co-existence of the old-use and new-use technology (in a particular location or frequency range) is not possible due to interference. In other words, there is a co-ordination problem which requires action from multiple parties. This is not the case for the nationwide mobile bands, where MNOs are generally the highest-value users of the spectrum, which means economic efficiency is achieved through trading among the MNOs (which can be done on a bilateral basis, without requiring any extensive wider co-ordination). An alternative way of framing this issue is in terms of technology neutrality. Where licences are technology neutral and the technical conditions permit operation of the higher-value user, the ability to trade may render AIP-based ALFs unnecessary for promoting economic efficiency. This applies to trading of licences between MNOs, but may not apply to trading of licences in other commercial spectrum bands with different types of use (where licence conditions may not be aligned). We note in this context that not all spectrum users may be able to respond quickly to incentives provided by AIP (e.g. the change in use of the 700MHz band from terrestrial broadcasting to mobile took from 2013 to 2021 to implement). AIP may not therefore be appropriate in all such instances, but its careful consideration is likely to be warranted.

For public-sector spectrum, there is an argument that users may not face the opportunity cost of holding their spectrum without AIP-based ALFs. The extent to which ALFs do impose the opportunity cost on public-sector spectrum users is debatable. If HM Treasury does not conduct value-for-money assessments on proposals from different departments for funding to cover their spectrum costs, then there is potentially no benefit in applying AIP to spectrum used by the public sector. We note that the Public Sector Spectrum Release (PSSR) programme has successfully made available various bands for mobile use that were previously used by the public sector, including 40MHz in the 2.3GHz band and 190MHz in the 3.4GHz band (auctioned for mobile use in 2018 – see Section 3.2.3).[180] We understand that AIP-based ALFs imposed on public-sector spectrum were a large part of the rationale for the PSSR (and risk of future increases in ALFs), although the extent to which the PSSR was exclusively driven by AIP considerations is unclear.

180 The PSSR programme initially aimed to release or share 500MHz of spectrum for civilian use by 2020 (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/518307/Advice_to_Government_-_CLEAN_-_PSSR_Target_Mar2.pdf). This was later increased to a target of 750MHz of spectrum by 2022; https://www.ukgi.org.uk/workcs/public-sector-spectrum-release-programme/

It is important to emphasise that while we have argued that there is not clear evidence that ALFs are needed to promote efficient use of *mobile* spectrum, our reasoning may or may not be applicable to other spectrum bands supporting different types of usage. This point also applies to the arguments made in the remaining subsections, where we focus on the current ALF approach as applied to mobile spectrum.

5.3.3 Approach to calculating ALFs for licensed mobile spectrum

Risk of ALFs being above market value when first set

Ofcom recognises that it is difficult to calculate market value accurately. As described in Section 5.3.1, Ofcom estimates market value using auction benchmarks.[181] In its 2100MHz ALF decision, Ofcom states that "*reaching our view has involved considerable exercise of our judgement, reflecting the fact that trying to determine a forward-looking estimate of market value for a specific spectrum band is not a precise science*". Given this imprecision, and since there is an asymmetric risk of setting ALFs too high as opposed to too low, Ofcom adopts a conservative approach when using its judgement to interpret the evidence of auction benchmarks. Nevertheless, there remains a risk that ALFs are set above market value.

It is especially hard to estimate market value for bands where there are no recent UK auction benchmarks in relevant spectrum bands, which means that Ofcom must fall back on international benchmarks (and relativities with the band in question). Prices paid in any auction will reflect a particular set of market conditions (at a specific point in time), as well as the auction design and licence conditions (see Section 5.2.1). Outcomes can also be influenced by irrational or strategic bidding behaviour. As such, the degree to which many auction benchmarks are informative of forward-looking market value in the UK (at a given point in time) will be debatable.

Our view is that Ofcom's approach to calculating ALFs does attempt to account for the above issues (e.g. by tiering auction benchmarks into different levels of informativeness, or discounting certain benchmarks altogether). Furthermore, Ofcom's approach is consultative, allowing MNOs to challenge its judgements; we note that in multiple cases, Ofcom's final fee decision has been (at least somewhat) lower than its initial proposed decision (i.e. Ofcom has adjusted its proposed fees downwards in light of MNO comments).[182] Moreover, as already noted, Ofcom's approach deliberately aims to be conservative.

Given the above, we consider it unlikely that Ofcom is inadvertently setting ALFs above market value when it first determines the fees. We note that there have been no instances to date of mobile spectrum licences being return to the regulator in the UK. However, it remains the case that, even if

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181 As stated in AIP principle 7 of the SRSP, Ofcom "*will take account of observed market valuations from auctions and trading alongside other evidence where available*" when setting ALFs. To date, however, Ofcom has only used auction benchmarks when setting mobile ALFs.

182 The 900/1800MHz ALFs were decreased several times over many consultation stages. 2100MHz FDD ALFs were decreased slightly in the decision relative to the consultation, and 2100MHz TDD ALFs were removed altogether.

Ofcom's approach for setting ALFs is reasonable, a key issue is that prices are determined at a given point in time, and market value can evolve. This is discussed further below.

Risk of periodic reviews of ALFs lagging behind the evolution of market value

Market value can change over time as spectrum requirements (and market conditions) change. Accordingly, Ofcom states that it will conduct periodic reviews of ALFs.[183] However, there is a risk of the periodic reviews lagging behind market requirements, meaning that the ALFs being paid by MNOs are based on outdated market values. For example, we note the following:

- In 2019, ALFs for UKB's 3.4GHz and 3.6GHz spectrum licences were set based on the results of the 3.4GHz auction in 2018. Ofcom set ALFs at the same level for both 3.4GHz and 3.6GHz on the basis that these bands would have the same long-term use. However, in the 2021 3.6GHz auction, spectrum sold at a much lower price per MHz than it did in the 3.4GHz auction (see Figure 5.6 below). It may therefore be argued that ALFs for the 3.4GHz and 3.6GHz licences were set too high. Indeed, as discussed in Section 5.3.5 below, in an effort to reduce barriers to trading, Ofcom recently decided to require UKB to 'pay off' the future ALFs due on its 3.4GHz and 3.6GHz licences through a single lump sum of equivalent value for each band. Notably, the 3.4GHz auction price is used to calculate the lump-sum value for 3.4GHz ALFs, and the 3.6GHz auction price is used to calculate the value for 3.6GHz ALFs.

- The 800MHz band typically attracted strong demand in Europe, as the only available sub-1GHz band harmonised in Europe for 4G use. The subsequent release of 700MHz spectrum for mobile use in Europe, in addition to the ability to refarm, or dynamically assign, 900MHz spectrum between different generations of mobile technologies, means that the price premium for the 800MHz spectrum may not reflect its value or that of other sub-1GHz bands in future. Indeed, as shown in Figure 5.6 below, prices paid in the UK's 700MHz auction in 2021 were considerably lower than those paid at the 800MHz auction in 2013. Given that the 800MHz price was a key factor in setting ALFs for 900MHz, 1800MHz and 2100MHz licences, it may be argued that fees in these bands should be reviewed.

Figure 5.6 shows the price of auctioned spectrum bands in the UK, as reported by Ofcom when setting the ALFs for 2100MHz spectrum in 2021. The prices are expressed as a lump-sum value for a 20-year licence, on a per-MHz basis. The market clearing price of spectrum at auction forms the basis of Ofcom's calculations for ALFs.

183 In Section 6 of the SRSP, Ofcom states: "*we will propose to conduct a fee review only where the evidence suggests that a review would be justified, including evidence of a likely and sufficiently material misalignment between the current rates and the opportunity cost of the spectrum for fees*". In its 900/1800MHz 2018 ALF decision, Ofcom notes that it would "*be unlikely to review [the 900/1800MHz] ALFs in the next five years save in very exceptional circumstances*". See paragraph 5.64–5.65 and 6.20.

Figure 5.6: Prices from recent UK mobile spectrum auctions (in April 2021 prices) [Source: Ofcom,[184] 2022]

Spectrum band	Auction date	Price (per MHz) in GBP million
700MHz	March 2021	14.1
800MHz	March 2013	37.0
2.3GHz	April 2018	5.4
2.6GHz	March 2013	6.2
3.4GHz	April 2018	7.9
3.6GHz	March 2021	4.2

While there is a risk that periodic reviews mean that ALFs lag behind market value, there is a benefit to licensees in having certainty over what level of fees will be charged in the longer term: regular updates to ALFs in response to market events would reduce the predictability of future costs for MNOs, with potential knock-on effects for incentives to invest in their networks.

5.3.4 Strategic bidding in auctions

As discussed in previous sections, the level at which Ofcom sets ALFs is guided by prices paid in UK auctions. There is therefore a risk of bidders acting strategically in auctions if it is known (or expected) that auction prices will affect their own, or competitor, ALFs in future for another frequency band. This 'circularity risk' argument also applies to trades, if Ofcom might use the price of a trade to guide ALFs in future.[185,186]

5.3.5 Impact of ALFs on spectrum trading

A key charge made against ALFs for mobile spectrum is that, not only are they unnecessary for promoting efficiency, but that they also actively inhibit trading, and thus act as a barrier to achieving economically efficient outcomes. Various arguments as to why ALFs inhibit trading can be advanced, which we assess below.

The existence of ALFs may inhibit trading

Where ALFs apply to mobile spectrum, these must be factored into the private valuation calculations of both the buyer and the seller in any potential trade, introducing an additional degree of complexity (and therefore cost) into the transaction. Where a trade involves two licences being swapped, and the licences have different levels of ALF and/or different periods over which the ALFs apply, the

184 Table 4.1, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/229428/1900_2100-mhz-statement.pdf

185 Ofcom considers this risk in the SRSP (paragraph 4.264). Ofcom has 'reflected this risk' in AIP Principle 7, which states that it will "*interpret market valuations with care and not apply them mechanically*" (see also paragraphs 5.62 to 5.67 of the 900/1800MHz 2018 ALF decision).

186 We note that there may also be a corresponding 'circularity benefit': a party that has little need for spectrum on offer in an auction may be tempted to drive higher prices (in order to increase the fees paid by its competitors), but it may be deterred from doing so if it knows that the auction outcome will have an impact on the ALFs payable on its own spectrum.

additional complexity applies to both valuations which must be conducted by each party. We note that this will generally be the case for trading of mobile spectrum between MNOs, except where the trade is for identical amounts of spectrum in the same band (e.g. for defragmentation purposes).

However, we do not consider this additional complexity to be a material barrier to trading in principle: it is straightforward in theory to calculate the impact of a defined set of ALFs on a private valuation (through suitable adjustments to a net present value calculation).

It may be argued, however, that the above assumes a 'pure economics' view of the world, in which private valuations are calculated on an economically rational basis, without consideration of factors such as real-world budget constraints or the varying preferences of financial managers/investors. As described below, Ofcom has recently decided to align ALFs (and other licence conditions) for certain spectrum in the 3.4–3.8GHz band, noting that "*H3G and at least one other MNO have told us that they have had difficulties in agreeing trades in the band due to the disparity*".

Case study: UKB/Three spectrum in the 3.4/3.6GHz bands

Following consultation, in October 2022, Ofcom decided to vary UKB's 3.4GHz and 3.6GHz licences so that they align with the terms of the licences in the 3.4GHz and 3.6GHz bands that were auctioned in 2018 and 2021 respectively.[187]

There is currently some degree of fragmentation across the 3.4–3.8GHz band which could, in principle, be removed through spectrum trading. However, Ofcom's consultation states that "*H3G [i.e. Three] and at least one other MNO have told us that they have had difficulties in agreeing trades in the band due to the disparity between the terms of auctioned licences and the terms of the UKB Licences*".

UKB's licences were subject to ALFs, whereas the recently auctioned 3.4GHz and 3.6GHz licences will not be subject to ALFs until 2038 and 2041 respectively. Ofcom states that these differences "*could potentially lead to a complex and protracted negotiation and unnecessary transaction costs. This could act as a potential barrier to trading.*" As such, to remove barriers to trading, Ofcom has decided to require UKB to 'pay off' the future ALFs due on its licences (to 2038 or 2041) through a single lump sum of equivalent value for each band. The calculation of each lump sum is based on auction prices in the relevant band. That is, the lump-sum value for the 3.4GHz ALFs is based on the 3.4GHz (2018) auction price and the lump-sum value for the 3.6GHz ALFs is based on the 3.6GH (2021) auction price. ALFs paid by UKB since those auctions are offset in full (i.e. payments for 3.4GHz in July 2019, July 2020 and July 2021, and for 3.6GHz in December 2021).

Ofcom also decided on further measures to align UKB's licences with the other 3.4GHz and 3.6GHz licences, including changing the revocation period and fee payment start date, removing spectrum leasing from the 3.6GHz licence, and moving 3.9GHz spectrum into its own separate licence.

187 https://www.ofcom.org.uk/consultations-and-statements/category-2/aligning-licence-terms-in-the-3.4-3.8-ghz-band

Whether the level of future ALFs may inhibit trading

As discussed in Section 5.3.3, Ofcom can periodically review the level of ALFs in order to reflect changes in market value over time. This creates uncertainty as to what the ALF liability associated with any particular mobile spectrum licence will be in future years.

An example potentially comes from the 2015 trade of 1400MHz licences from Qualcomm to Vodafone and Three. The sale was undertaken via a sealed bid process, and it was known that ALFs were likely to apply from 2023, but the level of these ALFs was highly uncertain.

In our view, this constitutes the best argument that ALFs act as a trading inhibitor: uncertainty on the future level of ALFs makes it difficult for different parties to agree on commercial terms for a trade.[188] Although we note that a trade was nonetheless completed in this case, this uncertainty would be eliminated from similar potential trades in the future if ALFs were to be removed, or replaced by investment commitments (although clear rules would need to be defined on which spectrum the investment commitment applies to, and what would happen if the spectrum were traded).

5.3.6 Impact of ALFs on network investment incentives

Some mobile stakeholders in the UK have claimed that imposing high ALFs reduces their level of network investment, an argument also made in some academic papers.[189] The argument made is that high ALFs reduce free cashflow and thereby reduce the funds available for investment.

However, this argument is inconsistent with standard economic theory, which considers that if the expected return on an investment exceeds the cost of capital, then it should be possible to fund that investment. The cashflow position of the MNO is not generally considered to be a determining factor, in that the MNO should (if necessary) be able to raise the required funding through capital markets, so long as the investment is expected to return a profit. In this context, the ALFs do not affect whether the investment is profitable, and therefore the decision on whether to invest should be independent of the (existence, and level) of the ALFs.

It has been argued that this theoretical view does not hold in reality, for example because:

- Whether or not it is economically rational, MNOs have to operate within defined capex budgets (commonly referred to as ‘envelopes’) and/or meet annual free cashflow targets, etc.[190]

188 Furthermore, as discussed in Section 5.3.4 above, there is a ‘circularity’ issue if it is known (or expected) that the future level of ALFs will be affected by the trade price.

189 See public MNO responses to Ofcom’s public consultations on ALFs; https://www.ofcom.org.uk/consultations-and-statements/category-2/annual-licence-fees-2100-mhz-spectrum

190 As evidence of MNOs operating within capex budgets, see our discussion of the outcome of the 800MHz and 2.6GHz auction in 2013 in Section 5.2.1. As discussed in that section, it appears to us that capex constraints were a likely reason that led to O2 not winning any 2.6GHz spectrum in the auction. Telecoms

- MNOs may not be able to raise any additional debt funding without losing their credit rating (and thus increasing their weighted average cost of capital (WACC))

- Capital markets may be less optimistic on an investment's expected return, and so may be unwilling to lend in relation to investments that an MNO would have undertaken if it had the free cashflow available to do so.[191,192]

- There may be an information asymmetry between the MNOs and lenders, arising from uncertain costs, demand and returns for investment. As external parties, lenders in capital markets do not have as good information on MNOs' prospects as the MNOs themselves, and the cost of debt financing will also include compensation for the risk that the external party incurs in lending to the MNO.

A large body of academic research has considered the empirical link between cashflow and the level of investment.[193] Various conclusions have been drawn from the empirical research, and so the extent of any relationship between the two is unclear.

In summary, our view is that there is no conclusive case that ALFs reduce investment. There is not good evidence to suggest that removing (or reducing) ALFs will guarantee significantly more investment in marginal areas.

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operators interrupting their dividend payments to fund investment projects could also be adduced. For example, BTEE interrupted its dividend payment for two years, from 2019 to 2021, to create capacity for its FTTP investments. See https://www.ofcom.org.uk/__data/assets/pdf_file/0021/237504/bt.pdf and https://www.bt.com/about/investors/individual-shareholders/dividends.

Furthermore, as described in Section 3.2.6, MNOs have maintained capex levels over the last decade, while ARPU has been declining in real terms. Given these trends show no clear signs of reversing, it may be argued that MNOs' capex budgets will come under increasing pressure.

191 It can also be argued that ALFs impair investment, to the extent that investors perceive that the ALFs have an impact on the MNO's ability to generate a stable return – that is, ALFs may increase its WACC. However, we consider this effect to be marginal.

192 As described in Section e3.2.6, Ofcom's 2022 discussion paper on the future approach to mobile markets reports that two MNOs (Three and Vodafone) have had a ROCE below their WACC in recent years.

We also note studies reporting that investment capital is harder to secure for telecoms operators in Europe than other peer markets, and that, as a result, Europe has invested less per capita in its telecoms networks over the last decade than the USA has. See Section 4.1 of GSMA's *The Mobile Economy – Europe – 2022* (https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/10/051022-Mobile-Economy-Europe-2022.pdf) and Figure 1-20 of ETNO's *The State of Digital Communications 2021* (https://etno.eu/library/reports/95-state-of-digi-2021.html).

193 A sample of relevant literature on the subject includes: Janssen, M. and Reynolds, P. (2018), *Is pricing spectrum at market value good for consumers?*, CEG Global, https://www.ceg-global.com/uploads/PDFs/White%20Papers/DPTelecoms_SpectrumMarket.pdf; Williamson, B. (2018), *Keeping an eye on the prize – investment in mobile networks to deliver coverage, capacity & the 5G strategy: A reappraisal of recurring spectrum fees* (paper for EE), Communications Chambers, http://www.commcham.com/pubs/2018/5/3/recurring-spectrum-fees.html; Lewellen, J. and Lewellen, K. (2016), *Investment and cash flow: new evidence*, Journal of Financial and Quantitative Analysis, Vol. 51, No. 4 August 2016, pp. 1135–1164; Chen, H. and Chen, S. (2012), 'Investment-Cash Flow Sensitivity Cannot Be a Good Measure of Financial Constraints: Evidence from the Time Series', *Journal of Financial Economics*, 103, https://www.sciencedirect.com/science/article/abs/pii/S0304405X11001929; Kaplan, S. and Zingales, L. (1997), 'Do Investment-Cash Flow Sensitivities Provide Useful Measures of Financing Constraints?', *Quarterly Journal of Economics*, 112, https://academic.oup.com/qje/article-abstract/112/1/169/1870889?redirectedFrom=fulltext

We do, however, take the view that it is inconsistent to argue both that:

- ALFs do not have an impact on investment incentives, and
- MNOs may respond to a direct cost (of an ALF) in a different way to an opportunity cost (of being able to trade a spectrum licence).

In both cases there is an 'economics' view and a 'real-world/practical' view of the impact that ALFs would have on MNO incentives. To argue that ALFs do not affect investment incentives but are necessary in order to encourage trading appears to apply the 'economics' view in one instance and the 'real-world/practical' view in the other (without a clear rationale for doing so).

AIP-based ALFs could, however, act as a disincentive for innovation, as higher ALF levels suit licence holders with a proven business model more than new entrants/innovators. In particular, there may be an impact on investment incentives for innovators (that would not otherwise be using the spectrum), as opposed to MNOs (which would be using the spectrum and paying ALFs in any event). In such a scenario, the predicted returns on the innovative investment would need to cover the incremental cost of the spectrum (i.e. ALFs). The higher the cost of that spectrum the less innovation (by non-MNOs) might therefore occur. Furthermore, such innovators will calculate only their private returns (in relation to their own costs) and the decision to innovate will not fully incorporate any positive externalities and values to others in the value chain (e.g. content providers, consumers, wider societal impacts).

5.3.7 Impact of ALFs on retail prices

The arguments set out in the previous section (regarding whether ALFs reduce investment) largely also apply to the question of whether ALFs put upward pressure on retail prices. According to standard economic theory, the ALFs paid by MNOs are sunk costs, and therefore should not be passed on to subscribers in the form of higher retail prices. However, as with the impact on investment, some may argue that this is not the case in reality (i.e. higher ALFs can lead to higher retail prices for consumers).[194]

Several published reports and pieces of academic research have explored the empirical link between spectrum costs and consumer prices. Various conclusions have been drawn from the empirical research: while some studies have found that there is no significant link,[195] others have drawn the opposite conclusion.[196]

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194 We note that Ofcom's 2100MHz 2021 ALF decision (paragraph 5.7 (b)) recognises that ALFs could lead to higher consumer prices, but that this is not certain. However, Ofcom considers that "retail prices should reflect all input costs including the resource costs of spectrum, and this does not represent a market failure, or markets failing to work in the interests of consumers". See also paragraph 5.47ff.

195 Cambini, C. and Garelli, N. (2017), 'Spectrum fees and market performance: A quantitative analysis', *Telecommunications Policy*, Vol. 41 (5–6), pp.355–366.

196 Nera Economic Consulting (for the GSMA) (2017), *Effective spectrum pricing: supporting better quality and more affordable mobile services*, https://www.gsma.com/spectrum/wp-content/uploads/2017/02/Effective-Spectrum-Pricing-Full-Web.pdf

As with the effect of spectrum fees on investment, our view is that there appears to be no conclusive case that ALFs increase retail prices.[197] We note that this may be an area of less concern anyway, given that mobile prices in the UK are relatively low compared to other developed markets.[198]

As in the previous subsection, our view is that, to argue that ALFs do not have an impact on retail prices but are necessary in order to encourage trading appears to apply an 'economics' view in one instance and a 'real-world/practical' view in the other (without a clear rationale for doing so).

5.4 Potential distortion of competition

The focus of this study is on market mechanisms as applied to currently licensed mobile spectrum bands in the UK, as well as how the current mechanisms might need to change to reflect future developments in the mobile market. As noted in Section 5.3.2, the recommendations that we set out in Section 6 are relevant to market mechanisms applying to public mobile spectrum, and will not be applicable to other wireless services (e.g. fixed links, private business radio) without review of the market circumstances surrounding those other uses.

However, even though the approach to managing spectrum other than licensed mobile spectrum (licensed or unlicensed) is not the subject of this report, it is relevant to briefly consider the impact of potential disparities between the management approach to licensed mobile spectrum and other spectrum in which similar services to some of those delivered over public mobile networks are being offered.

Where spectrum is available to other users and is not subject to market mechanisms, it may be available at a significantly lower cost, or at no cost (e.g. where it is priced only on the basis of administrative costs, or is available on a lightly licensed, or licence-exempt, basis). Although the conditions for use of lightly licensed or licence-exempt spectrum are usually designed around low-power, short-range connectivity, it is possible that as services converge and the services being offered begin to overlap with those offered by MNOs, distortions may begin to arise. Below we briefly consider an example related to spectrum allocated to satellite services, especially where terrestrial use of the satellite spectrum ('complementary ground component'[199]) is permitted.

Spectrum used for satellite services

Some existing satellite services are allocated in spectrum bands that are also technically suitable for the provision of terrestrial mobile services. Within the satellite industry there has been demand for flexibility in how existing satellite spectrum can be used, including deployment of ground

197 Other relevant literature includes: Bauer (2001), 'Spectrum auctions, pricing and network expansion in wireless telecommunications'; Park, Lee and Choi (2010), 'Does spectrum auctioning harm consumers? Lessons from 3G licensing'; Janssen, M. and Reynolds, P. (2018), *Is pricing spectrum at market value good for consumers?*, CEG Global, https://www.ceg-global.com/uploads/PDFs/White%20Papers/DPTelecoms_SpectrumMarket.pdf

198 In 2020, Ofcom found that UK mobile prices were lower than those in France, Germany, Italy, Spain and the USA; https://www.ofcom.org.uk/__data/assets/pdf_file/0022/189112/pricing-trends-communication-services-report.pdf

199 For example, in the 2GHz and other similar bands. See https://docdb.cept.org/download/2623

components. For example, the 2GHz mobile satellite spectrum (1980–2010MHz paired with 2170–2200MHz) was licensed on a pan-European basis to satellite operators Inmarsat and Solaris (now part of Echostar) in 2009. However, in 2016 Inmarsat sought to use its assignment of 2×15MHz to deliver broadband services to aircraft through the use of both a satellite component and a terrestrially delivered complementary ground component (CGC).

Ofcom authorised this use in October 2017, through amended technical conditions and the imposition of AIP-based ALFs. The ALFs were set at GBP554 000 per 2×1MHz nationally, or as a range of annual prices between GBP825 and GBP64 000 per 2×1MHz per base station . Although these fees are significantly lower than the ALFs for mobile spectrum (e.g. on a national basis, around one third of the per-MHz fees for the 1800MHz band), to reflect the less-developed ecosystem and increased risk to the licensee, the principle of AIP has been applied.

Without the application of market mechanisms (in this case AIP) there would be a distortion of competition between different types of licensee, and the potential for undue windfall gains in relation to any future trade.

We note that there is also potential for other bands allocated to satellite services to be used to deliver services that compete with those provided by MNOs in licensed mobile spectrum. For example, low Earth orbit (LEO) satellite systems may address the same market of connectivity to vehicles and other IoT applications as MNOs do, and might also offer direct connectivity to smartphones via the latest 3GPP (Release 17) developments.

Whilst noting that the focus of this report is not on spectrum other than licensed mobile spectrum, we consider that *a priori* it would seem sensible for market mechanisms to apply in a similar manner to other such spectrum bands. It is important to note that this does not mean the spectrum should necessarily incur the same ALFs: under the current approach these should be determined by the opportunity cost based on the demand for the spectrum, rather than the end-user service that is provided.

6 Recommendations on adapting market mechanisms for the future

This section sets out our overall conclusions and recommendations from the study.

- In Section 6.1 we present our conclusions on the existing market mechanisms (auctions, trading and pricing) as currently implemented for licensed mobile spectrum, and our recommendations on if/how/when these might be adapted to suit the future mobile spectrum landscape.
- In Section 6.1.4 we briefly look ahead to discuss potential future innovations in mobile spectrum management.

6.1 Summary of key conclusions and recommendations

A high-level summary table of our key conclusions is shown in Figure 6.1.

Figure 6.1: Summary table of key conclusions [Source: Analysys Mason, 2022]

Question		Trading	Auctions	Pricing
Does the basic philosophy articulated in the Cave report still support use of a market mechanism of this form?		Yes	Yes	No
Is the overall market mechanism approach and current implementation of that approach optimal in terms of both promoting spectrum efficiency and avoiding undue problems/risks?		No	No	No
Are there alternative possible options that might lead to better outcomes, in relation to ...	... the overall market mechanism approach?	No	No	Yes
	... the way the overall market mechanism approach is currently implemented?	Yes	Yes	Yes

Further explanation for our key findings in this summary table is provided below.

- The mobile market (and the telecoms market more broadly) has changed significantly since the Cave report was written, and further, potentially disruptive, changes can be foreseen in the remainder of this decade.
  - Regarding ***trading*** and ***auctions***, our view is that the fundamental economic philosophy articulated in the Cave report continues to support these market mechanisms (hence a 'yes' in the first row)

  - Regarding ***pricing***, however, we take the view that the philosophy underpinning the pricing of nationally available public mobile spectrum no longer applies (hence 'no' in the first row for pricing). Given that mobile trading is possible between mobile network operators (MNOs), and between MNOs and other third parties, our view is that pricing is not needed as an extra incentive to support economic or technical efficiency in mobile spectrum.[200]

- In the second row of the table we ask whether each market mechanism, as currently implemented, is optimal. We conclude that the answer is 'no' for all three mechanisms: this is because, in each case, we identify potential issues and concerns in relation to the promotion of economic and/or technical efficiency and/or avoiding undue problems/risks. The strength of these concerns varies. For example, the issues we identify are relatively minor for trading, but more major for auctions in the context of the type of new mobile spectrum that might become available in the remainder of this decade, particularly at higher frequencies. For pricing, we consider that the arguments for ALFs being needed to provide an extra incentive for more-efficient use are weak.

- Given that the situation is not optimal, in the third row we ask whether there are any alternative options to the overall approach for each market mechanism that might lead to better outcomes.

  - Regarding ***trading***, we answer 'no': our view is that the principle of trading is sound, and that this remains the case when taking account of possible future technological and market changes over the remainder of this decade.

  - Regarding ***auctions***, we consider that alternative options (e.g. administrative assignment, shared spectrum access, DSA) do exist and may be relevant (or at least form an important part of any solution) in some situations – specifically, in higher frequencies, or in bands where mobile use is permitted alongside other existing uses, or where there is expected to be some form of shared use in the future.

    - In the mobile market, higher frequencies will principally be used to increase network capacity where needed (i.e. in locations where the highest portion of data traffic is generated). If not deployed to provide contiguous coverage over wide areas, there is a question over whether any newly assigned mobile bands should be auctioned for mobile use on a national basis, or whether there will be greater opportunities for sharing between future mobile use and existing (or future) services allocated within those bands. Auctions of sub-national mobile licences might allow mobile use to co-exist within the same spectrum also used for other services but in geographically separate locations (or, the mobile licensed portions of spectrum might co-exist with existing use in the same geographical location, if feasible to do so).

200 While we argue in this report that there is not clear evidence that ALFs are needed to promote efficient use of *mobile* spectrum, it is important to note that our reasoning may or may not be applicable to other spectrum bands supporting different types of usage.

- For lower-frequency spectrum (e.g. bands deployed for nationwide coverage) our view is that auctions of national licences will continue to be the best approach. As such, we answer 'no' in the summary table, as we think that auctions must continue to play an important part in any future solution. We note that Ofcom's recently proposed approach to the 26GHz and 40GHz bands is different from that adopted when auctioning the most recently assigned national mobile bands (at 700MHz and 3.6GHz). Hence, Ofcom's thinking is already moving in the direction of increasing geographical utilisation of spectrum via area-defined licences for higher frequency bands. This approach also potentially provides a means of reducing scarcity in spectrum that might apply in situations where licences are only made available on a nationwide basis.

– Regarding ***AIP-based pricing***, we answer 'yes': our view is that there are alternative options which may lead to better outcomes.[201] Namely:

  - removing ALFs for existing licences, and issuing any future mobile licences (i.e. in new bands that might become available for mobile use) with indefinite terms, and
  - considering whether societal benefits from greater access to mobile services can be realised through a 'non-cash' approach for currently licensed mobile bands, in which, for example, ALFs are replaced by MNO coverage/investment commitments that can contribute to economic growth and increased spectrum utilisation.[202,203]

- The final row asks whether there are alternative options to the way the overall market mechanism is currently implemented that might lead to better outcomes. For all three market mechanisms, we answer 'yes'.

  – Regarding ***trading***, it may be beneficial to introduce market-led leasing (i.e. the ability for MNOs to lease specific frequencies for a defined time period, rather than to make an outright trade). Local access licensing has largely addressed the disadvantages of not having a leasing framework (except where longer leases may be required or in certain edge cases, e.g. where an MNO is using the spectrum but a local user could derive greater value from it), but enabling MNOs to make leasing agreements directly with third parties would provide additional flexibility. A potential alternative to the market-led leasing approach might be for Ofcom to modify/clarify the existing local access licensing framework to achieve a similar result. That is, the MNO could be allowed to charge a fee to the local licence applicant as a condition of

201 Both of these alternative options are likely to lead to equivalent or better outcomes (relative to the current ALF arrangement) in terms of spectrum efficiency/utilisation and the quality and price of available mobile services.

202 That is, a commitment from MNOs to achieve specified coverage or service quality levels, or to invest specified amounts in their networks (above and beyond the investment that would have occurred on a commercial basis). Illustrative examples of investment commitments that could contribute to economic growth are provided in Section 6.1.3.

203 We note that if government chose to replace ALFs with some other form of taxation of radio spectrum, then the viability of investment commitments alongside any such measure would need to be considered carefully (e.g. rigorous cost–benefit analysis to determine any potential investment commitment).

granting permission (in cases where the MNO would otherwise have a right not to grant permission, e.g. because it has plans to use the spectrum).[204]

– Regarding ***auctions***, Ofcom needs to take due care when designing them, and consideration of objectives, and the design of an auction to meet the objectives of the award, will continue to be needed on a band-by-band basis as new bands are investigated for mobile use, especially where there may be a possible opportunity for sharing between mobile and other (existing or new) services in the same bands. Arguably, not all mobile spectrum auctions in the UK to date appear to have maximised spectrum efficiency, e.g. certain aspects of the 800MHz/2.6GHz auction are often cited as an example here. Shared/local licensing is also expected to become more relevant as there is a shift to higher frequencies. However, we note that Ofcom is already focused on addressing both issues relating to auction design and the incorporation of shared/local licensing, and as such there is no need for a change of approach per se.

– Regarding ***pricing***, the answer is implicitly 'yes', given that we consider the argument for using AIP-based ALFs to provide extra incentive for more efficient use to be weak. We note that raising the level of ALFs above opportunity cost would not increase spectrum efficiency, and would risk licensees returning their spectrum to the regulator (and deterring other operators from subsequently acquiring that spectrum from the regulator).

In the following subsections we provide further details on our conclusions and recommendations for each market mechanism, and the suggested timing for implementing any changes.

6.1.1 Trading

The principle of spectrum trading is sound. Views that the volume of trades for (mobile) spectrum have been low are sometimes expressed, but this may say as much about expectations for trading as it does about how well or badly trading is functioning. Trading serves a useful purpose and, with some minor caveats, there are no material barriers to executing trades within the trading regime itself.

- Overall, as for auctions, we find that despite market changes, the current trading framework is broadly suitable. This remains the case when taking account of expected future trends

- It may be sensible to introduce market-led leasing (i.e. the ability for MNOs to lease specific frequencies for a defined time period, rather than an outright trade, which is not currently possible for mobile spectrum), though local access licensing has largely addressed the disadvantages of not having a leasing framework (except where longer leases may be required or in certain edge cases, e.g. where an MNO is using the spectrum but a local user could derive

[204] We have not sought to examine the relevant legal framework in detail, but we note that this alternative approach might, in practice, be simpler to implement if there were concerns (for example) over how liability (including criminal liability) would be dealt with in a leasing arrangement. For example, we understand that criminal liability (including a criminal breach of the Wireless Telegraphy Act) cannot be contracted away to a third party.

greater value from it). If market-led leasing was introduced, liability arrangements between the MNO and the leaseholder would need to be carefully considered. A potential alternative to the market-leasing approach might be for Ofcom to modify/clarify the existing local access licensing framework to allow the MNO to charge a fee to the local licence applicant as a condition of granting permission.

6.1.2 Auctions

Overall, we find that auctions work well and should continue to form an important part of the management of mobile spectrum in the UK. There are caveats around how auctions are implemented, and there are important questions about the extent to which mobile spectrum licensing should be based on nationwide licences with local access provisions versus shared licensing. But overall, auctions have worked well and will remain a useful tool.

With anticipated market changes, auctions will continue to be the best option available for assigning new nationwide spectrum licences, but they must be well designed:

- Auctions should be simple, transparent, and not introduce artificial scarcity.
- Coverage obligations can continue to be incorporated into auctions where appropriate, but this should only be undertaken with due care and attention, since there is a risk of distorting efficient outcomes (e.g. skewing the auction in favour of the party that can deliver the coverage obligation most efficiently, rather than necessarily being the most efficient user of the spectrum).
- However, coverage (and network quality more generally) is a primary focus of government policy via DCMS, and so an alternative means of introducing such obligations may be needed if auctions are not used for this purpose. In fact, the incorporation of coverage obligations in auctions may be less of a concern in future, as new mobile bands are in general likely to consist of higher frequencies.

Most of the mobile bands auctioned to date have been suited to deployment over large areas of the UK landmass, and hence nationwide licensing has been the most appropriate approach. As mobile technologies evolve to use even higher frequency bands to achieve wider contiguous bandwidths, there will be a decline in the extent of 'wide-area' coverage being provided by new bands alone (but potentially these higher bands will be designed to work alongside lower bands, creating technical advantages for the lower bands, such as better coverage at the cell edge). Higher bands will thus be most useful to serve densely populated areas (which are distributed across the UK nations). Nevertheless, we do not find that the more-limited geographical deployment of certain bands (e.g. 2.6GHz and 3.4–3.8GHz) indicates that alternative approaches (e.g. regional licensing) would have produced a better outcome in these bands.

In future, players with LALs will be able to access unutilised spectrum in these bands (e.g. within certain geographical areas), which will be beneficial in expanding the geographical utilisation of these bands to more locations.

As the shift to higher frequencies progresses, at some point regionally defined and/or local/shared licences may become more appropriate than nationwide exclusive licensing via auction, although the precise boundary line remains unclear (e.g. above 4GHz?, above 7GHz?, above 26GHz?). Auctioning wide-area licences in certain locations (e.g. city centres) is still expected to represent the most transparent approach where demand exceeds supply, but FCFS administrative assignment of local licences elsewhere (as Ofcom is proposing for 26GHz and 40GHz) is a sensible approach for higher-frequency spectrum.

There are ways in which further innovation could be applied to the licensing of high-frequency spectrum, such as the 'club spectrum' model[205] proposed by Real Wireless in its January 2021 report for the UK SPF on licensing the 26GHz band.[206] However, the applicability of such approaches would need to be considered by Ofcom on a case-by-case basis, weighing up the benefits against additional complexity and any further costs (as indeed Ofcom has done in relation to club spectrum in the 26GHz and 40GHz bands).

6.1.3 Pricing

Spectrum pricing is the market mechanism that has worked least well to date, and concerning which there is most contention looking ahead. It is not clear that the net effect is beneficial in terms of promoting efficiency, at least in relation to mobile spectrum. This leads us to consider whether there are alternative options that might be preferable.

Links between ALF and network investment and/or retail prices

- The theoretical and empirical arguments have been well rehearsed, but there is no conclusive case that ALFs reduce investment (and to the extent that they might, it is hard to argue that the behaviour (of withholding profitable investment) by MNOs is economically rational). Removing ALFs will not guarantee significantly more investment in marginal areas.
- Likewise, there is no conclusive case that ALFs increase retail prices. This could be considered less of an area of immediate concern anyway (as mobile prices are currently relatively low in the UK).
- It may be the case that ALFs are inhibiting spectrum trading, but their impact here is also not clear cut. The best arguments for ALFs being a trading inhibitor centre around uncertainty about the future level of ALFs.

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205 Ofcom describes this model in its consultation on mmWave spectrum (see https://www.ofcom.org.uk/__data/assets/pdf_file/0027/237258/mmwave-spectrum-condoc.pdf) as follows: "*A club model would enable licensees to access spectrum specifically assigned to them, as well as to temporarily access spectrum in the same band which has been licensed to another operator, but which is not currently being used in a particular area. Users who do not have dedicated frequencies would be unable to access spectrum in this way – access would be restricted to those who have their own spectrum holdings (i.e. who are part of the 'club')*".

206 https://uk5g.org/media/uploads/resource_files/26GHz-The-opportunity-for-a-fresh-approach-to-licensing-Real-Wire_JNiG1U9.pdf

Whether ALFs provide incentive to use spectrum efficiently

- Given the increasing reliance of consumers and businesses on mobile devices, it is very unlikely there will be a higher-value alternative use for bands currently used for mobile. This implies that the only users likely to be more efficient than the current users are other MNOs with the ability to deploy networks at scale.

- The ability to trade means that MNOs already face the opportunity cost of their spectrum. If they do not trade then either they are already the most economically efficient user, or there are countervailing strategic reasons (which ALFs are unlikely to override).

- As such, in our view ALFs for mobile spectrum are not needed to promote efficient use of the spectrum, although ALFs/AIP for other sectors of wireless use (e.g. terrestrial fixed links, or public-sector spectrum) may remain very relevant as a tool to create incentives for more efficient spectrum use, and to discourage spectrum hoarding.

Options for currently assigned mobile spectrum

In future, options might include removing ALFs entirely for currently assigned mobile spectrum (thus issuing perpetual licences for all existing bands[207]) or replacing ALFs with coverage/ investment commitments.[208] These options are discussed below.

Option 1 – Remove ALFs

The argument for following this approach centres on ALFs being unnecessary as an additional incentive to promote spectrum efficiency. Removing them would not result in any loss (relative to the current situation) in terms of spectrum efficiency and potentially offers gains if barriers to trading are reduced.

In addition, the removal of ALFs would not result in any loss in terms of spectrum utilisation, and potentially offers gains if there is an increase in investment. Finally, removal of ALFs would not result in any loss in terms of retail prices, and there is a possible gain if retail prices were to fall.

We note that increased financial stability of MNOs could help to prevent a worse outcome from materialising across any of these three areas (spectrum efficiency, spectrum utilisation/investment and retail prices).

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207 Licence durations might also vary between shared and exclusive use spectrum. Our recommendation is that future auctioned licences for mobile spectrum assigned on an exclusive basis to operators could be awarded with an indefinite term, meaning that prices paid at auction would reflect the indefinite duration of the licence. However, licences for mobile use of spectrum shared with other uses might be awarded with a shorter duration (as Ofcom is doing currently) as a way of encouraging innovation and providing greater flexibility for a future change in spectrum use.

208 These options could potentially also be combined by, for example, reducing the cash component of ALFs and requiring an amount equal to the remainder to be invested in networks in a prescribed manner. However, we have not considered such permutations in detail.

Option 2 – Adopt a 'non-cash' (or hybrid) approach, e.g. replace ALFs with coverage/ investment commitments

The current (i.e. market-value based) ALFs paid by MNOs for currently assigned spectrum could instead be levied in the form of coverage or investment commitments from MNOs, with the aim of improving network coverage/quality (a stated policy goal of government). Consideration could also be given to applying this approach to future assigned bands, such that the price paid at auction would be a lump sum for a licence of indefinite duration, but with commitments to invest set out in the auction rules (similar to the way that coverage obligations have been set out accompanying previously auctioned licences).[209]

This approach as applied to currently licensed spectrum would effectively 'ringfence' the amounts that the MNOs would have paid on ALFs and instead require these funds to be invested in network infrastructure. Investment commitments for any future mobile bands would be determined on a case-by-case basis as any new bands came to market. As noted earlier the report, MNOs are expected to pay around GBP330 million in ALFs in 2022, which coincidentally is also the amount that was invested in 5G networks in 2020.[210] Following this approach could therefore help to approximately double current 5G investment levels.[211]

As described earlier in this report, MNOs are facing significant challenges in deploying 5G. The roll-out of 5G increases the upfront investment needed from MNOs, and also increases operational costs, but MNOs will see decreasing returns on invested capital if retail prices continue to decline in real terms. Furthermore, it will be challenging for MNOs to deploy 5G massive MIMO technology using mid-band spectrum in the 3.4–3.8GHz range deep into rural areas, due to the low density of users (and hence low revenue opportunity). In other words, although mid-band spectrum has been licensed nationally to the MNOs, they may not achieve the same levels of geographical utilisation of this spectrum compared to lower bands. However, it is 5G massive MIMO technology using mid-band spectrum that is required to provide the 'full 5G' services which offer a step change in speed and performance of mobile broadband, lowers the cost per GB, and enables new mobile use cases and applications. Accordingly, some form of investment commitment from MNOs, public subsidy or other intervention to achieve higher levels of population and landmass coverage of full 5G services across the UK seems beneficial. In this context, an approach which diverts GBP330 million per year into investment commitments may be an appealing option.

209 Option 2 could be modified such that there is a cap on the commitment to invest, with any excess remaining as a cash ALF. This would ensure that the maximum amount that MNOs can redirect into investment is the same for all players.

210 The total amount invested in mobile network infrastructure in the UK in 2020 was GBP1.8 billion, of which GBP330 million related to 5G, but the proportion of total investment that is for 5G will certainly increase in future.

211 In practice there would not be a doubling, since additional network infrastructure would also incur additional opex in future years, which would have to form part of the investment commitment.

There are several other possibilities for investment commitments (beyond extending population and landmass coverage of full 5G services), and the following subsection provides some illustrative examples.

In summary, this option would:

- offer benefits in terms of achieving the objectives of DCMS and some of Ofcom's statutory duties, by driving improvements to digital infrastructure
- offer benefits to government in contributing to its stated targets and potentially contributing to economic growth
- (potentially) offer benefits to the MNOs: although if the starting assumption is that the investment commitment would match the 'cash' ALF outlay then the only difference would be that all MNOs would be left with higher-quality networks, in which case MNOs would only benefit if there was an assumption of incremental revenue
- offer benefits to consumers through enhanced network quality, with a possibility of some downward pressure on retail prices.

We also note that this option would not result in any loss (relative to the current situation) in terms of spectrum efficiency or retail prices.

There would be several challenges in implementing this option, which would need to be carefully explored by industry if taken forward, for example:

- avoiding distortions to competition, which may be more likely to arise in the context of a coverage commitment rather than an investment commitment (e.g. '95% coverage' may cost some MNOs more to achieve than others, depending on the coverage of their existing networks)[212]
- avoiding gaming or otherwise diminished benefits, which may occur with investment commitments where it is hard (though likely not impossible) for Ofcom to gauge the extent to which investment would have occurred commercially and therefore define how much investment is generally incremental to 'business as usual' for each MNO.

It is unclear whether the geographical spectrum utilisation/investment gain in Option 2 is likely to outweigh the (potentially broader but less certain) gains in Option 1. The choice between these two options would constitute an important policy decision for Ofcom and the government, which should ideally be supported by a rigorous cost–benefit analysis.

Option 2 seeks to improve network coverage/quality, while Option 1 does not. We note that if Option 1 were to be followed, then further parallel consideration of approaches to improve the coverage/quality of mobile networks may be desirable.

212 Potential mitigations of competition impact in relation to investment commitments, if (following its analysis) Ofcom considered these to be of concern, could include capping the amount of ALF 'payable' via investment commitment, with the remainder remaining as a 'cash ALF'. However, the details of any such approaches would require careful consideration.

Illustrative examples of the potential benefits of Option 2

The shift from low- to mid-band mobile spectrum to secure 5G technology/capacity advances causes a dramatic increase in the cost of coverage. It follows that the extent of commercially provided full 5G coverage using mid-band spectrum is likely to fall significantly short of matching current low-band mobile coverage. The areas that do not receive mid-band coverage will therefore not benefit from the same economic growth potential that full 5G would deliver.

As noted above, driving increases in population and landmass coverage of full 5G services, such as those delivered using 3.5GHz, could be a possible use of investment commitments of the type proposed under Option 2.

However, there are several other possibilities for investment commitments which could support public policy objectives that the market would not otherwise deliver. For example, funding network resilience against extreme weather events, and improving connectivity across key transport routes. Diverting ALFs into investment commitments of this kind offers a number of advantages:

- The modular nature of mobile networks means that investments in improvements of the types illustrated below can be undertaken over a long period of time rather than necessarily all having to happen (at high up-front cost) at the same time
- Competent supervision (via Ofcom) should ensure value for money, and
- Everything is in place for money to flow efficiently and quickly to the right players.

The boxes below provide two purely illustrative examples of possible infrastructure investment commitments, and what they could deliver for the country.[213]

213 Note that Analysys Mason does not intend to imply that these illustrative examples are the best possible uses of such funds or that any work has been undertaken to cost the implementation of these suggestions (and subsequent comparison to the current level of ALFs over a defined time horizon (e.g. 10 to 20 years)).

Example investment commitment 1: enhancing connectivity for rail and key transport routes

Travelling by train allows passengers to work or to relax – but both these activities increasingly require good connectivity. Mobile signal is notoriously poor in trains, with train routes frequently passing through notspots and the available data rates generally being low. 5G solutions could deliver highly reliable and super-fast connectivity to antennas on top of train carriages, which would then relay 5G and Wi-Fi signals within the train. With funding re-directed from the ALFs (and with support from MNOs and the government ensuring co-operation from the railway industry), passenger experience on the main train lines could be transformed within a few years.

Similarly, supporting MNOs to accelerate the extent and quality of coverage of key transport routes would encourage economic growth in a variety of ways, for example by supporting the advent of self-driving electric vehicles and the capacity needed for future demand for infotainment and other mobile services.

Example investment commitment 2: enhancing network resilience and sustainability

Mobile networks are a major user of electricity, and their power requirements are growing as data usage increases (for example, as further RAN technology is deployed at mobile sites in order to accommodate traffic growth). Operators aim to become carbon-neutral by sourcing their electricity from "green" providers, but this only addresses the problem to the extent that on-grid green energy is available.

Funding from government has the potential to help operators in their drive towards sustainability. Funding could be used by operators both to increase their self-generation at some base stations (e.g. using solar-panel and wind-turbine technologies) and to reduce their overall power usage (e.g. by upgrading to more-efficient equipment and using sensing/AI technology to put equipment into power-saving sleep mode).

Relatedly, mobile network outages can have a significant economic impact (as well as a significant social and public safety impact), something that has been highlighted by recent storms in the UK. Grid-power cuts are a key cause of mobile network outage, and so there is a growing interest among government and policy makers in increasing the resilience of the UK's mobile networks to such outages. This could be achieved by deploying (a sufficient level of) battery back-up at (a sufficient number of) mobile sites. However, this is an expensive undertaking, which may not be commercially viable for operators. ALF funding could be used to support a programme in which MNOs gradually add battery back-up across their networks, to reach a specified level of RAN autonomy (i.e. a certain number of hours of battery-powered back-up operation in the event of a power cut). The installed battery back-up could also allow mobile base stations not to draw power from the grid when there is an unforeseen peak in demand.

6.1.4 Timing of changes to the market mechanisms

The case is strong that now is the time to review, adapt and modernise all of the market mechanisms. There are changes that can be made in the short to medium term that can contribute to the promotion of spectrum efficiency, and potentially also to economic growth, as outlined above. More ambitious changes could be considered in the long term, and now is a good time to invest in long-term research into these possibilities that could, for example, deliver spectrum sharing at scale. We outline some preliminary future considerations in this regard in Section 6.2 below.

6.2 Future considerations

As the market has evolved, so too has the academic discussion surrounding it, giving rise to novel and alternative concepts of market mechanisms. Figure 6.2 below gives examples of alternative market mechanisms which are at varying stages of academic discussion and implementation.

Figure 6.2: Overview of alternative market mechanisms [Source: Ofcom,[214] CATO Institute,[215] 2022]

Market mechanism	Description	Examples
Depreciating licences	The licence holder decides what value it places on the spectrum holding. A fixed depreciation rate (e.g. 10%) is applied to this valuation to calculate the annual fee for the perpetual licence. However, the licensee is obliged to sell the licence to any parties willing to pay the value assigned by the incumbent licensee	None
Foothold auctions	Spectrum licences are periodically re-auctioned to approximate the depreciating licence exchange system outlined above. Incumbent licensees are given a price advantage in the auction or awarded compensation if they are outbid	Considered in the context of the FCC's 3.5GHz award, but ultimately not used
Congestion triggers	Should excess demand emerge for licences which were originally assigned administratively at cost, then higher fees or other congestion management methods can be triggered	In Hong Kong, a 'Spectrum Utilisation Fee' is triggered if there is 75% occupation of a spectrum band[216]

As part of our study we have considered alternative market mechanisms of the kinds outlined above. However, many of these are still at a nascent stage, and in our view it is currently unclear whether these solutions would be relevant for the UK mobile market to address the identified shortcomings of the existing approaches. As such, our recommendations in Section 6.1 above focus on the existing

214 Paragraph 7.24, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/208773/spectrum-strategy-consultation.pdf

215 https://www.cato.org/regulation/fall-2017/redesigning-spectrum-licenses

216 https://www.coms-auth.hk/filemanager/common/ta20110923.pdf

market mechanisms (auctions, trading and pricing) as currently implemented for licensed mobile spectrum, and whether/how these might be adapted to suit the future mobile spectrum landscape.

In a future market, it can be envisioned that mobile spectrum might be licensed on a shared, rather than exclusive use basis, particularly at higher frequencies, and mobile devices might operate seamlessly across frequency bands for which different licensing arrangements would apply. This type of environment might require regulatory action to change market mechanisms in line with a move away from exclusivity in spectrum use. For example, the mobile industry might be required to invest in developing appropriate technology to use shared spectrum in mobile networks, and investment in database technology could also be considered.

Actions might also be needed by regulators to ensure that incentives for efficient spectrum use are aligned across different types of use, and that any competition concerns are addressed. Through the set-aside of the 3.8-4.2GHz band for shared access use, Ofcom has already introduced a situation in which spectrum that might be of value to MNOs (on a licensed basis) and can support services that compete (to a certain extent) with those offered by MNOs is available under a licensing approach that is not subject to market mechanisms.

Given market trends and our recommendations for adapting the market mechanisms, the spectrum management landscape (for licensed mobile spectrum) may look somewhat different in the future.

- Regarding ***trading***, the shift to mobile use in higher frequency bands (alongside other market developments such as the new types of players and business models enabled by 5G and future technologies) raises the possibility of more trading in future (for example, if auctions are used to award multiple, area-specific licences, rather than a more limited number of national licences). Where licences are issued on a more localised basis for higher frequencies there may be scope for increased volumes of trades or leases at lower value, which could potentially be achieved through a more automated system involving less friction and lower transaction costs. Automated systems such as databases might also assist in the management of bands where there is sharing between incumbent and new uses of a band (for example, a band in which there is incumbent use outside of urban locations, and where mobile use is concentrated primarily in urban locations where levels of data traffic are high). We might also see more sharing between different forms of use within the same band – licensed mobile together with licence-exempt technologies, for example.

- Regarding ***auctions*** and ***pricing***, the shift to mobile use at higher frequencies (alongside other market developments discussed in this report) raises questions about the most suitable approach for assignment of new spectrum and how it is priced.

  – We have argued that, where there is scarcity of supply, new spectrum should be made available at full market value, and hence an auction approach is generally the most suitable. If this is not the case (e.g. spectrum is assigned administratively at a price below market value), then there is a major risk of windfall gains being made by speculators through trading in the secondary market (and therefore efficient use of spectrum not being maximised)

– Conversely, where there is no scarcity of supply such that market value is low, there is a clear rationale for administrative assignment with ALFs. In this case, annual fees could be set on a cost-oriented basis (though it is clearly important for Ofcom to operate as efficiently as possible, such that cost-based prices are low). We note that it is less likely, but possible, that there will be a scarcity of supply for harmonised mobile spectrum at higher frequencies, depending on the demand for this spectrum, which is still emerging. Where local/shared licensing may be more appropriate, an automated process for managing the spectrum (e.g. database-technology approaches) may be beneficial, and Ofcom has already indicated its intention to move in this direction

– Conceptually, there is a third type of supply situation which lies between the previous two binary options, and could be of interest in future, particularly at higher frequencies. Namely, the scarcity of supply in a given location may vary over time, or be contingent on the way in which the spectrum is used (which might vary geographically, or over time). Where this is the case, this could warrant consideration of innovative/dynamic pricing arrangements. For example, if licensees could agree to certain conditions (e.g. co-existence/sharing conditions, low transmission power) which enable greater co-existence and hence reduce the level of spectrum scarcity, then this could be reflected in lower pricing levels. This could potentially be done on a dynamic/automated basis using database technology.

Another possible alternative approach that could be explored is how market mechanisms might be used in innovative ways to help meet other policy challenges – for example, sustainability/net-zero policy objectives.

Suggested next steps

The focus of this study has been the three market mechanisms as currently applied to licensed mobile spectrum bands in the UK. We recommend that further work could be conducted to undertake a detailed assessment of how the market mechanisms might stand up to a variety of potential future developments in the mobile market. Such potential future developments could include:

- Extensive network densification through the proliferation of small cells (particularly indoors), which may create demand for access to shared spectrum to enable new models, such as neutral-host provision or self-deployment by building owners
- The emergence of a national-scale wholesale mobile network provider (or providers)
- Large amounts of public-sector spectrum (e.g. spectrum currently reserved for the Ministry of Defence, such as the lower 2.3GHz band) being made available on a shared access basis
- Particular bands becoming subject to demand from a range of user types (e.g. MNOs, private and local operators and short-range applications), requiring consideration of the extent to which licensed, lightly licensed and unlicensed spectrum can achieve the greatest balance.

For the avoidance of doubt, we are not advocating for any of these particular developments, but highlighting them as potential future scenarios which could be investigated in relation to the market mechanisms.

Further work could also consider if/how emerging and novel market mechanisms (such as 'depreciating licences' and 'foothold auctions') might be used in the context of these future developments.

Annex A Master list of arguments against market mechanisms

This annex provides a list of arguments against the market mechanisms as currently implemented. This list was initially collated by techUK.

The arguments put forward, their implications and all wording in this section are provided by techUK and do not in all cases represent Analysys Mason's views.

A.1 Section 1. What has changed in the market circumstances over the past 20 years that challenge the underlying assumptions of Cave and how might this, and the new challenges ahead, change the approach today?

The transformation of mobile spectrum from a tradable to non-tradable asset

Figure A.1: Master list of arguments against market mechanisms – Section 1 [1/6] [Source: Analysys Mason, 2022]

#	Argument
1.1	The rise of mobile broadband from just another commercial service in the market to an indispensable national infrastructure essential to a modern digital economy and social life
1.2	The emergence of the smart phone, driving a relentless rise in mobile data demand (that has sucked all liquidity out of any nascent spectrum market that was already squeezed by intense competition)

Implication – Have these change rendered the current Ofcom approach to spectrum pricing an inoperable tool in driving economic spectrum efficiency?

Spectrum band economics inverting the logic of where spectrum pricing can best drive economic spectrum efficiency

Figure A.2: Master list of arguments against market mechanisms – Section 1 [2/6] [Source: Analysys Mason, 2022]

#	Argument
1.3	The rise in the spectrum of bands used for cellular mobile networks leading to the emergence of a differentiation of mobile spectrum bands between "coverage" bands and "capacity" bands (each having radically different technical and economic characteristics)
1.4	The investment capacity of mobile network operators being overtaken by the rise in the cost of delivering higher performing national broadband mobile networks needing higher spectrum bands and having those radically different economic and technical characteristics
1.5	The emergence of large areas of the UK with unused "capacity" band spectrum
1.6	Far reaching changes in the mobile network operator's business models from telephone usage revenues being the dominant source of MNO profits to the dominance of access

#	Argument
	subscriptions with telephone and text messaging usage bundled in (changing the equation for coverage and capacity investments in the various mobile spectrum bands)

Implication: Has where spectrum pricing is most beneficially applied been inverted by these changes, since it is having no impact in improving economic spectrum efficiency on most valuable spectrum, whereas economic spectrum efficiency can be as low as zero (for higher bands outside of urban areas) where the spectrum pricing tool could be beneficial but has not been designed to apply?

Severing of the link between the MNO optimal economic outcome and the national optimal economic outcome in spectrum exploitation

Figure A.3: Master list of arguments against market mechanisms – Section 1 [3/6] [Source: Analysys Mason, 2022]

#	Argument
1.7	Net neutrality regulation that has severed the link between spectrum/access networks and the "over-the-top" digital services and therefore between spectrum prices and overall economic spectrum efficiency

Implication: Does this change tell us that spectrum price signals are no longer 100% dependable in driving the most economic use of mobile spectrum?

Global mobile industrial economics diluting and distorting spectrum "market mechanism" economics

Figure A.4: Master list of arguments against market mechanisms– Section 1 [4/6] [Source: Analysys Mason, 2022]

#	Argument
1.8	The demise of competing cellular mobile technologies and in its place the rise of a single globally harmonised technology with huge scale economies (dwarfing spectrum pricing effects)
1.9	The emergence of dominant global smartphone suppliers and chip vendors in vast complex global supply chains determining the value of spectrum bands via which come as standards in devices and smartphones
1.10	The synchronisation of mobile network innovation into 10-year cycles (that has been sustained over four generation since 1G) has of itself generated spikes in the value of new spectrum suitable for a next generation technology
1.11	The regulator corralling MNO's into "an innovation pack" for the purpose of releasing new spectrum through a single time and resource efficient spectrum auction (re-enforcing of the price spike effect noted in 1.10) and also delaying the timeline for the MNO's who are most ambitious to invest early
1.12	The introduction of more complex technology (e.g., TDD) that makes it harder for radically different uses of the spectrum to be introduced on spectrum, whatever its potentially higher economic value

Implications: Do these changes suggest a need for a more holistic spectrum economic model that brings to together "spectrum market" and "industrial" economic forces"?

Changing competitive landscape affecting mobile spectrum use

Figure A.5: Master list of arguments against market mechanisms – Section 1 [5/6] [Source: Analysys Mason, 2022]

#	Argument
1.13	The de facto foreclosing of the market to new entrant national MNOs since 2002 due to the intensity of competition, the high infrastructure cost barrier and more challenging MNO business models
1.14	The decline in coverage obligations being attached to UK licenses for new mobile spectrum acquired at spectrum auctions and replaced by the emergence of government subsidy to redress rural coverage market failure
1.15	The complex environment not proving to be conducive to the emergence of the hoped-for rewards from the market mechanisms of maximising economic spectrum efficiency and emergence of a spectrum market in which innovators could secure the spectrum, they wanted when they wanted it
1.16	The revealing of capacity "market failure" to deliver economic spectrum efficiency in circumstances where one of the MNOs in the UK market did not acquire 2.6 GHz capacity spectrum at a spectrum auction
1.17	Mobile connectivity within homes and offices becoming largely displaced by Wi-Fi links to the fixed broadband networks, leading to unforeseen congestion, that in turn has put pressure on expanding spectrum for Wi-Fi through non-market mechanisms
1.18	The re-emergence of huge investments in multiple low earth orbit satellite systems using spectrum acquired at significantly lower cost than cellular mobile operators are required to pay through the market mechanisms and both addressing the same market of connectivity to vehicles and, in the future, even to smartphones
1.19	The emergence of separate tracks for public and private 5G spectrum as a result of the market mechanisms not delivering high value mobile spectrum for innovators in the UK

Implications: Do independent regulators need a wider range of tools than just the three market mechanisms for mobile spectrum and if so, how are those tools to be aligned (harmonised) to ensure a level playing field?

Future influences on mobile spectrum policy

Figure A.6: Master list of arguments against market mechanisms – Section 1 [6/6] [Source: Analysys Mason, 2022]

#	Argument
1.20	The growing engagement of governments, coming from a strategic perspective, in the successful deployment of next generation mobile infrastructures and their security and resilience

#	Argument
1.21	Rising mobile coverage digital divide across the UK with rising data speeds performance due to higher spectrum bands having to be used to support the higher performing infrastructures
1.22	Glimpses of a 6G world of pervasive AI that would require a rebalancing of market competition and co-operation in the use of mobile spectrum to maximise the optimisation rewards for consumers and businesses as well as MNO's
1.23	Weakening of the UK's post-Brexit influence on European and thus "ITU Region 1" and global spectrum harmonisation but providing the UK with more flexibility to change its approach to spectrum regulation more rapidly to seize future opportunities

Implications: Are we on the threshold of the next mobile spectrum revolution?

A.2 Section 2. Do the market mechanisms deliver what it is claimed they deliver?

2a) Do full market value based ALF's (Annual License Fees) deliver on better economic spectrum efficiency?

Figure A.7: Master list of arguments against market mechanisms – Section 2a [Source: Analysys Mason, 2022]

#	Argument
2a.1	Applying AIP based annual fees to spectrum used for mobile broadband reduces national economic efficiency by depleting investment in coverage and capacity needed to support an expanding "over the top" digital economy (that is not reflected in spectrum prices)
2a.2	AIP based spectrum pricing disincentives buyers of unused or under-utilised spectrum or fragmented spectrum thus impeding the free flow of spectrum between public and private networks to the detriment of economic (and technical) spectrum efficiency
2a.3	Lack of trades of mobile spectrum (other than equivalent swaps) shows continuous economic spectrum efficiency improvements are not taking place as a result of spectrum pricing (and is impeded by it as noted in 2a.2)
2a.4	New spectrum awards and trading have enabled a rebalancing of spectrum holdings between MNOs, without involvement of ALFs. None of the recorded mobile spectrum trades has been as a result of AIP spectrum pricing "incentives"
2a.5	Transfers of spectrum between today's mobile operator's is a zero-sum game in respect of economic spectrum efficiency as they are all providing the same access service to the same over the top services using the same interoperable technology
2a.6	The economic power of global standards has made market driven alternative "proprietary" network technology innovation not feasible and therefore spectrum pricing contributes nothing to network technology innovation
2a.7	Spectrum efficiency gains from incentive pricing has limited theoretical upside anyway as any innovative new usages have to fit within existing restrictive interference masks that are set by the state of the art of earlier generations of technology
2a.8	Mobile broadband has become an essential national service. Thus spectrum pricing delivering more economically efficient "other uses" on any appreciable scale is not a politically plausible possibility as, if significant "prime" mobile spectrum were to be transferred by a mobile operator to a non-mobile use as a result of spectrum pricing, it would be so hugely disruptive to consumers, businesses, and the wider economy that the political and reputational backlash would be immense

#	Argument
2a.9	It is not commercially plausible for the most valuable mobile spectrum at 2.1 GHz and below needed for national coverage to ever be traded as a result of spectrum pricing as a mobile operator would be unable to retain enough of its market share just relying only upon coverage from spectrum in bands above 2.1 GHz (with coverage as little as 20% of the UK)
2a.10	Mobile bands above 2.1 and below 3.8 GHz are unlikely to ever be traded as a result of spectrum pricing because the alternative mobile bands that lay above 3.8 GHz (e.g., 26 GHz) are hugely more expensive to use for replicating high-capacity mid band coverage
2a.11	For spectrum bands in commercial use, the Cave report recommends spectrum trading as the main mechanism to ensure that the spectrum is used efficiently. Therefore, Ofcom's approach is inconsistent with the recommendations made in the Cave report
2a.12	As MNOs' profitability has declined, their willingness to pay for spectrum has also reduced. However, this lower willingness to pay is not reflected in Ofcom's approach to setting ALFs
2a.13	The Cave report recommends setting ALFs based on the information from spectrum trades. However, spectrum trading remains relatively limited, which means that there are limited relevant reference points for setting ALFs
2a.14	Market value can change over time, creating a risk that periodic reviews of AIP/ALFs lag behind market requirements
2a.15	Regulators rely primarily on evidence from past auctions as a benchmark for both the absolute and relative value of spectrum. However, the number of observations is small, and some that Ofcom has relied on recently go back as far as 2013
2a.16	Benchmarking internationally also indicates that auction receipts can vary substantially dependent upon auction timing, auction design, market structure and expectations (e.g., comparisons of Italy to UK recent 5G auctions)
2a.17	In the USA, there is an expectation that auctioned licences have indefinite duration, which avoids the uncertainty, and potential negative consequences, which result from the UK's approach of setting fixed initial terms for licences and an expectation that an ALF will subsequently be applied, but at an unknown level
2a.18	In an attempt to address the issue of limited availability of data on relevant benchmarks, Ofcom has used evidence on relative prices from other countries in combination with UK auction results. However, country-specific circumstances may mean that international benchmarks not informative of the relative spectrum values in the UK
2a.19	Setting ALFs based on AIP can have negative downstream consequences for consumers, including higher retail prices
2a.20	The significant information asymmetry between the regulator and MNOs, who will have a much better understanding of their private value
2a.21	If the AIP is set below the market value, then there will be excess demand and (absent trading) a sub-optimal user may continue holding the spectrum. As a result, there will be a potential welfare loss, due to the difference in the value of the blocks between the optimal and sub-optimal users
2a.22	A Game theoretical analysis done recently for Vodafone demonstrated the limitations of a spectrum trading regime and how decisions based on pure profit maximisation of each operator may lead to suboptimal levels of trading. That is, trading levels that are lower than the consumer welfare enhancing maximum. Market uncertainty and the use of calculation of ALFs further reduces trading below the optimal levels

2b) Do full market value based ALF's deliver on better band or geographical spectrum efficiency?

Figure A.8: Master list of arguments against market mechanisms – Section 2b [Source: Analysys Mason, 2022]

#	Argument
2b.1	In areas of high traffic concentrations spectrum pricing plays no role in driving "band" spectrum efficiency. It is the relentless rise in customer data traffic demand that drives more efficient use of an MNO's mobile spectrum bands in those areas of high demand
2b.2	The Cave Report proposed Administrative Incentive Pricing should be on the most valuable mobile spectrum. It made sense in the circumstances of the time. But two major developments have reversed the natural logic: • "The most valuable" spectrum for national mobile broadband networks (largely coverage spectrum) is most valuable because it is "indispensable" to all the mobile operators to provide an indispensable national public service to consumers and businesses. As such AIP based ALF's can have no impact on maximising economic spectrum efficiency. • Conversely, it has not be targeted at spectrum (largely capacity spectrum) laying unused (zero spectrum efficiency) over very large areas of the country. Thus, AIP based spectrum pricing is failing to have any impact on economic spectrum efficiency at both ends of the traffic density demographics
2b.3	The technical framework within which mobile operators have to operate to avoid mutual interference cannot be changed unilaterally by a single spectrum user to improve spectrum efficiency whatever the value they place on their spectrum or the opportunity cost set by the regulator for annual licence fees
2b.4	The Cave Report contained a suggestion that spectrum pricing would incentivise a mobile operator to buy more spectrum efficient technology where the cost saved exceeded the cost of their incentive price fees. The displacement of proprietary standards by public standards produced by a single standards body made this no longer tenable as technology decisions in a global standards body are not in the least influenced by the ALF based spectrum price being paid by mobile operators from just one country
2b.5	ALF based annual spectrum fees are a potential impediment to co-operation between MNO's in working together in "Club Spectrum" type models (mutual opportunistic use of each other's unused spectrum) that could deliver far greater geographic spectrum efficiency of mid and high bands
2b.6	New and fundamentally different approaches to spectrum authorisation might be required to meet growing spectrum requirements in future (for example, spectrum sharing), but the focus of spectrum sharing tends to be on technical feasibility without consideration of how pricing tiers might be applied as an incentive for sharing (as seen in the USA)

2c) Do spectrum auctions always deliver the most efficient use of the spectrum?

Figure A.9: Master list of arguments against market mechanisms – Section 2c [Source: Analysys Mason, 2022]

#	Argument
2c.1	Auctions are a one-time link to economic spectrum efficiency valid only on the day of the auction (if at all) as "the ambition" giving rise to a higher bid is never turned into a license condition and the environment at the time of an auction is never stable over any length of time

#	Argument
2c.2	Anecdotal evidence reveals that bid prices at spectrum auctions are not always driven by ambitious business plan for exploiting that spectrum but commercial factors having nothing to do with spectrum
2c.3	There is no historic evidence that spectrum that was the subject of the highest bid at an auction has been any more economically efficiently used than the spectrum acquired at the same auction by those placing lower bids
2c.4	Spectrum auctions to-date have rewarded a very urban centric view of spectrum economic efficiency at the expense of maximising the non-urban economic exploitation of spectrum – a point that rises in importance as mobile bands rise in the radio spectrum
2c.5	The theory that the mobile operator making the highest bid reflects a greater ambition for the use of that band and therefore the greatest economic spectrum efficiency breaks down for mobile bands intended for “capacity” rather than “coverage” as mobile operators do not have a long-term plan of where and when “capacity” bands will ultimately be deployed at the time a spectrum auction is held
2c.6	A spectrum auction of higher mobile “capacity” bands leads to greater administrative cost, lengthy delay, and opportunity cost in terms of just-in-time action to deal with congested hot spots relative to alternative release mechanisms that have the same or better probability of economically efficient use
2c.7	The 4G 2.6 GHz spectrum auction failed to deliver the most economically efficient use of the spectrum when an MNO, who was the market leader, was unable to win spectrum in the 2.6 GHz auction as there followed a market failure in consumers switching to mobile operators who had successfully bid for the spectrum and able to offer higher capacity networks
2c.8	Regulators have used their monopoly powers to second guess the market when they set high reserve prices and some badly designed auctions have led to excessive prices
2c.9	The high cost of network densification will inevitably lead to the need for more infrastructure sharing and even market consolidation and, as such, the number of effective bidders is likely to diminish to the extent of calling into question the viability of holding spectrum auctions
2c.10	The “incumbents’ curse”: The value of spectrum may be distorted because operators of 3G/4G networks cannot afford not to get 5G spectrum and so be kicked out of the market. This would also apply to spectrum for 6G and other future generations
2c.11	Multiband auctions are overly complicated: To allow operators to acquire an optimum portfolio of spectrum, auctions may be for combinations of bands. However, defining the values of these and taking part in combinatorial auctions is a complicated process requiring a great deal of preparatory and academic work
2c.12	Auctions may lead to spectrum being left unallocated, resulting in significant inefficiency and welfare losses. This could occur if the reserve price is set too high, i.e., above all bidders’ valuations. For example, spectrum was left unallocated in auctions in Australia, India, Pakistan, etc.

A.3 Section 3. What is the opportunity cost of the AIP based ALF's and excessive auction fees in terms of benefit loss to consumers, wider economy, and society (with illustrative examples)?

Figure A.10: Master list of arguments against market mechanisms – Section 3 [Source: Analysys Mason, 2022]

#	Argument
3.1	The claimed economic efficiency from spectrum auctions has come at an excessive price of £27.5 billion over the three technology generations of spectrum auctions with no quantifiable gains in economic spectrum efficiency ever being proved to have taken place
3.2	The "market mechanisms" philosophy has been shown to have a "principled" blindness to the negative consequences of spectrum auctions on infrastructure investment. It was too lightly dismissed in the Cave Report as there was not enough evidence in 2002 as 3G networks were not first rolled out until 2003. The impact on investment has not even been brought up by Ofcom in any of their impact assessments for their spectrum auctions
3.3	The government is extracting "a profit" from the scarcity of spectrum that doesn't exist today as operators are forced by competition to keep up with better performing technology, but consumers have not shown themselves willing to pay a higher subscription for "the future potential" access to a next generation technology provides
3.4	Japan and China, who did not use spectrum auctions but alignment with their government's national infrastructure strategies, have more expansive deployments of more powerful mobile infrastructures better serving their economies and societies and reaping a high economic spectrum efficiency
3.5	Opportunity cost of the annual spectrum fees amounting to £6.6 billion over the next 20 years is investment displaced that, for example, could fund a super-Shared Rural Network that lifted the 2 Mb/s edge of network data speed up by one or two orders of magnitude to close the digital divide
3.6	If there were greater flexibility on mobile spectrum ALFs in the UK, as there is in France, other obligations could be better achieved in the UK, such as improving comprehensive 5G coverage
3.7	The minimum efficient scale for entry combined with difficulties in monetising value has not led to the entry that was surmised by Ofcom. The logic is that mobile networks are national and need national operators with national spectrum. However, that logic may no longer apply going forward and thus requiring a rethink of appropriate objectives in this area
3.8	Mobile operators pay roughly the same amount on license fees which is ultimately passed on to consumers resulting in higher prices

A.4 Section 4. What is the impact of Ofcom's competition policy and net neutrality regulation on the effectiveness of the market mechanisms?

Figure A.11: Master list of arguments against market mechanisms – Section 4 [Source: Analysys Mason, 2022]

#	Argument
4.1	Net neutrality has cut the correlation that once existed between spectrum acquisition and the value to the economy from the services the mobile network will support on that spectrum (as these are now largely carried over the top and in which the mobile operator has no financial interest to reflect back into auction bids or paying for ALF's priced at opportunity cost
4.2	Intense competition policy neutralises the incentive pricing policy as it blocks all possibilities of an MNO's releasing spectrum to third parties in case they turn into potential competitors
4.3	Intense competition policy erects commercial barriers to greater co-operation in the use of spectrum that could deliver higher spectrum efficiency in the circumstances where there are market leaders and/or struggling MNO's

A.5 Section 5. Can the market mechanisms distort competition between entities subject to the market mechanisms and those that are not?

Figure A.12: Master list of arguments against market mechanisms– Section 5 [Source: Analysys Mason, 2022]

#	Argument
5.1	Applying the market mechanism philosophy to the licensed mobile bands but not to the satellite bands is an emerging significant distortion of competition between new LEO satellite systems competing with UK owned cellular mobile networks as they will be addressing the same market of connections to vehicles, meeting even more intensive demands from driverless vehicles and possibly direct connectivity to smartphones in the future
5.2	Cave Report assumed the opportunity cost for satellite spectrum would be zero as satellites used exclusive spectrum that could be reused without limit by bringing new orbit slots into use. Yet in 2015 contention arose between the satellite and mobile for the exclusive use of spectrum at 28 GHz at WRC (15). The market mechanisms were not used to determining the most economically efficient use of the 28 GHz spectrum
5.3	Applying the market mechanism philosophy to the licensed mobile bands but only recovering administrative costs for local access spectrum is a potential distortion of competition and particularly addressing the industrial uses of 5G that could be met by 5G SA or private 5G
5.4	The emergence of "Verticals" having an interest in acquiring mobile spectrum for 5G has muddied the market mechanism approach in some countries, notably Germany
5.5	Cave Report assumed the opportunity cost would be zero for licence-exempt spectrum on the basis that interference is so localised that different spectrum users impose no material constraints on each other's transmissions, but rising demand for Wi-Fi in homes and the reach of Wi-Fi signals between dwellings has led to the band saturating and new bands being found without a market mechanism test

#	Argument
5.6	Fibre to the home competing with fixed wireless access (which includes mobile, IOT, satellites, FWA and Wi-Fi). The latter (mobile) is subject to the market mechanisms and associated fees which creates distortion in the market by loading more cost on one mechanism than another
5.7	Licensed spectrum is also competing with unlicenced spectrum (e.g., Bluetooth and Wi-Fi) to which market mechanisms do not apply. For example, a factory deploying a wireless system would potentially opt for Wi-Fi as a cheaper option than installing a 5G system for which it would have to buy spectrum at a cost

A.6 Section 6. Do the market mechanisms have any other significant negative unintended consequences?

Figure A.13: Master list of arguments against market mechanisms – Section 6 [Source: Analysys Mason, 2022]

#	Argument
6.1	The market mechanisms absolve the regulator from pursuit of "national interest" policy objectives, like supporting the UK government's spectrum proposals in their 2018 Future Telecommunications Infrastructure Review
6.2	Embrace of the market mechanisms by regulators leads to a separation between spectrum policy and creating the next generation mobile infrastructure technology standards that potentially leads to lost benefits for consumers and the economy through a lack of alignment of policy goals
6.3	The market mechanisms (as currently implemented) contain no "self-correction" mechanism for the mobile economy having been transformed over the past 20 years from a highly profitable / low-cost national mobile telephone infrastructure environment to a much lower profitable/high-cost large capacity mobile broadband infrastructure environment
6.4	Adherence to a set of market mechanisms principles 20 years old is a barrier to moving rapidly to seizing innovative regulators spectrum models made possible through the regulatory flexibility Brexit has enabled
6.5	The market mechanisms look inappropriate to carry into a 6G era of advanced AI managed resources that will require a high degree of co-operation between spectrum licensees to enable interconnected AI agents to maximally optimise overall performance and capacity to benefit of all from a scarce natural resource
6.6	The market mechanisms block better spectrum provisions at the extremes of rural coverage in those remote areas where only the Home Office ESN provided towers exist
6.7	A key objective of market mechanisms in the UK was to incentivise public sector spectrum holders to use spectrum efficiently, including releasing spectrum to the market. Although some bands have now been released where there was commercial demand (e.g., 2.3GHz and 3.4–3.8GHz), other similar bands have not yet been released (e.g., 26.5–27.5GHz)
6.8	Auctions require defined lots and long licences: Although theoretically technology neutral, in reality lots are designed around current technologies (for example, some 4G spectrum was allocated in 2×1.2 MHz blocks, which cannot be used for 5G or future technologies)
6.9	Occasionally there may need to be a significant reallocation of spectrum. In some circumstances this may be possible through the market (e.g., by spectrum trading). However, at other times it may be necessary for a comprehensive re-farming by taking spectrum back from licensees and reallocating, as suggested by Ofcom for the 40GHz band. This may not be possible under a market mechanism

A.7 Section 7. Do market mechanisms deliver the right spectrum when it is needed?

Figure A.14: Master list of arguments against market mechanisms – Section 7 [Source: Analysys Mason, 2022]

#	Argument
7.1	Adherence to the market mechanism of a spectrum auction leads the regulator corralling MNOs into an "innovation pack" and not enabling one innovative MNO wanting to move ahead of the pack to deliver their innovation soonest to the market
7.2	Auctions take a long time to organise
7.3	Reliance on auctioning spectrum leads regulators to not releasing some spectrum early on a local geographic basis in past national TV band clearance programmes
7.4	Not all spectrum users can respond quickly to incentives provided by AIP (e.g., the change in use of the 700MHz band from terrestrial broadcasting to mobile took from 2013 to 2021 to implement)

A.8 Section 8. Do the market mechanisms help or hinder innovation?

Figure A.15: Master list of arguments against market mechanisms – Section 8 [Source: Analysys Mason, 2022]

#	Argument
8.1	The ambition for the market mechanism in the Cave Report was that it would lead to a market in spectrum (where innovators could acquire the spectrum they want when they want it) but such a liquid market in national mobile spectrum has failed to materialise
8.2	The synchronisation of mobile network innovation into 10-year cycles creates spikes in the value of new spectrum that lifts the price well beyond the reach of other wireless innovations that then cannot secure the industrially mature spectrum they need
8.3	Ofcom themselves have concluded that the market mechanisms have not delivered enough mobile spectrum for innovation and have administratively set aside the 3.8–4.2GHz band for innovation but this is not the most economically efficient use of spectrum as the innovators have been placed in a band that is less advanced in the industry supply chain, thus reducing supplier choice and increasing cost (lower economies of scale) and MNO's are denied the possibility of making more economically efficient use of that spectrum
8.4	The high costs of industrially well-developed mobile spectrum have led Ofcom to persuade MNOs to loan their unused spectrum "free of charge" to innovators but significant innovations are hindered by the time duration of the loans being limited to 3 years and the process incurs long bureaucratic delays
8.5	It has been argued that spectrum is a fixed cost and therefore should not hinder decisions to innovate and invest. However, this is increasingly not the case. There is also an opportunity cost in using spectrum for one use over the other. The predicted returns to innovation will need to cover the incremental cost of spectrum and the higher the cost of that spectrum the less innovation will occur
8.6	Furthermore spectrum owners will calculate only their private returns to private cost and the decision to innovate will not fully incorporate the positive externalities and values to others in the value chain e.g., content providers, consumers, wider societal impacts if they are not monetised by the operator

#	Argument
8.7	Industrial and private network use: Pure market mechanisms will award spectrum solely to the bidder with the highest value, but this does not take account of the supply chain. Industrial use of spectrum may reduce costs but also prices for the onwards supply chain; the acquirer of spectrum would then see little benefit, but GDP as a whole may be significantly increased
8.8	AIP-based ALFs could act as a disincentive for innovation, as higher ALF levels suit licence holders with a proven business model more than new entrants / innovators
8.9	Ofcom's spectrum roadmap, published in March 2022, raises the prospect of accelerating innovation through spectrum sandboxes, but without clarity on how market-based prices might be shared amongst users in a shared spectrum environment; additionally, there is a risk of the industry not engaging with this sandbox initiative

Annex B Historical context of mobile technology evolution

Successive generations of mobile technologies introduced increased speeds and new capabilities:

- 2G supports CS voice services and short messaging service (SMS); data connectivity (i.e. PS data over IP) is possible via 2G technology variants called General Packet Radio Service / Enhanced Data rates for Global Evolution (GPRS/EDGE), which are hardware upgrades that some operators chose to deploy, but data rates are extremely limited.
- 3G supports CS voice services and SMS, as well as higher-speed IP data rates (generally considered to qualify as 'mobile broadband'.
- 4G supports both voice and data over IP connections and allows higher data rates than 3G.
- 5G is again all-IP and allows even higher data rates.

1G (launched in the 1980s)

Analogue cellular systems (now commonly referred to as the first generation, or 1G), introduced in the UK during the 1980s, enabled voice communication via handheld devices, representing a move away from landline phones for the first time. However, it was not until the launch of second-generation mobile systems (2G) in the 1990s, using Global System for Mobile Communications (GSM) digital technology in the UK and much of the rest of the world, that the number of mobile voice subscribers started to increase significantly. At the same time, consumers were introduced to mobile data services, through SMS, or text.

2G (launched in the 1990s)

2G mobile services were first introduced in the UK using spectrum in the 900MHz band (which was also the spectrum band used for the UK's 1G networks). Early 2G services focused on mobile voice services, initially provided by two national network operators (today's Vodafone and Virgin Media O2). As demand increased, the UK government led the way in Europe in making spectrum available for GSM use in the 1800MHz band. Two further national licences were offered, and assigned to Orange and One-2-One (subsequently T-Mobile); the move from two to four players aimed both to increase competition in the public mobile market and to make 2G services accessible to a wider subscriber base.

2G networks replaced the original 900MHz analogue 1G networks fairly quickly (analogue networks were closed in the UK in the mid to late 1990s). Conversely, 2G still exists in the UK market today.

During the period of 2G subscriber growth in the 1990s, various other networks and technologies existed, using their own dedicated spectrum bands, and providing 'professional mobile services'. These were data services offered to businesses and industrial users, such as radio paging, public

access mobile radio, and two-way radio systems for fleet management / vehicle tracking. These networks were used entirely for business radio purposes and not marketed at consumers. The addition of data capability to 2G networks would eventually lead to the decline, and closure, of these professional mobile network alternatives.

In the consumer market, mobile was becoming the preferred method of voice communication, and SMS became increasingly popular, leading to growth in mobile data usage.

3G (launched in the early 2000s)

By the late 1990s, 3G was under development, and demand for spectrum more broadly was increasing. It was also around this time that spectrum management approaches started to evolve away from the traditional 'command-and-control' approaches, with the introduction of AIP and auctions as a means of assigning licences.

The first major spectrum auction in the UK took place in 2000, when 3G licences using spectrum in the 2100MHz band were auctioned. The government choose to award five 3G licences (one more than the number of 2G networks in the market at that time), as a means of furthering competition, and creating a fifth 'new entrant' in the mobile market. The business plans for 3G launch were premised on 3G providing voice, video and data services, potentially with higher ARPU achievable through the offering of new data services.

Subsequent 3G launches (from 2003 onwards) focused initially on voice, before data services became more prevalent. The UK mobile market was still growing at this point, and the fifth mobile licence was awarded to Hutchison Three (now Three UK). The term 'mobile broadband' (MBB) was introduced in the 3G era with the evolution of 3G technology to high-speed packet access (HSPA). MNOs with 2G networks also evolved those networks in parallel, to deploy 2G-based mobile data technologies such as GPRS and EDGE.

Data traffic growth meant that additional spectrum was needed for capacity reasons – especially driven by data traffic volumes in urban locations. Meanwhile, rural areas were largely still reliant on 2G to provide sufficient reach for mobile communications.

4G (launched in the early 2010s)

By the time 4G was introduced, growth in mobile voice use was levelling off, but data traffic (including video) was growing fast.

The development of global 4G standards started during the mid-2000s. By this point, 3GPP had become the dominant global mobile standards body and the 3GPP 4G technology (LTE) was the first mobile standard to be implemented largely globally based on the same technology specification (since the 3G technology family included multiple technologies, adopted to varying degrees in different world markets). However, although LTE is deployed in most markets around the world, the frequency bands used for LTE deployment vary between markets. In most advanced markets,

including the UK, multiple frequency bands are used for LTE deployment, and some have different technology characteristics to others (for example, the 2300MHz, and part of the 2600MHz, band in the UK are used for LTE TDD technology, which has different characteristics to LTE FDD technology that is used in 700MHz, 800MHz, 900MHz, 1800MHz, 2100MHz and 2600MHz bands.

Annex C Key definitions and list of acronyms

This annex provides definitions for key terms related to the concept of spectrum 'efficiency' and spectrum 'utilisation' as used in this report. We also provide clarification on the way we use the term 'market mechanisms'. The annex concludes with a glossary of acronyms used in the report.

C.1 Definition of key terms used in the report

Efficiency

We use the terminology of 'economic' and 'technical' efficiency in a way which aligns with the Cave report, with broadly similar (but more concise) definitions:[217]

- **Economic efficiency** is maximised when spectrum is allocated to users that generate the greatest economic value from it.
- **Technical efficiency** refers to spectral efficiency (i.e. bit/s/Hz).

We note that other definitions of efficiency could also be considered. For example, 'energy efficiency' could be useful to consider in the context of environmental policy objectives.

We also use the concept of spectrum utilisation, defined as follows:

- **Spectrum utilisation** is maximised when there is minimal 'wasteful' use spectrum. There are three dimensions along which spectrum utilisation can be measured: frequency, space and time. For a given frequency range, geographical area and period of time, the highest possible utilisation would be where all of the frequency range is used across the entire area all of the time. As such, three measures of utilisation can be defined:
  - **geographical utilisation**: the level of spectrum utilisation measured with respect to the space dimension
    - if a mobile licence is nationwide, but only a fraction of the landmass is covered with the spectrum, this concerns geographical utilisation
  - **frequency utilisation**: the level of spectrum utilisation measured with respect to the frequency dimension
    - if a mobile spectrum licence is for 20MHz, but only 10MHz has been deployed, this concerns frequency utilisation
  - **time utilisation**: the level of spectrum utilisation measured with respect to the time dimension

[217] See paragraph 19 of the Executive Summary of the Cave report. The definition of technical efficiency provided in the Cave report includes concepts of both spectral efficiency and spectrum utilisation.

- this is considered less relevant in the context of mobile, but is included here for completeness.

Market mechanisms

In the context of spectrum management, the term 'market mechanism' is used in different ways by different stakeholders. For example, we note that some stakeholders may not consider pricing (based on ALFs set at full market value) to qualify as a market mechanism. Ofcom does refer to this form or pricing as a market mechanism, but also refers to spectrum liberalisation as a market mechanism (see Section 4.2). In line with techUK's terms of reference for the study, 'market mechanisms' refers to use of the following:

- **Auctions**: the assignment of spectrum licences through an auction process
- **Pricing**: the levying of AIP-based ALFs (i.e. ALFs set at full market value)[218]
- **Trading**: the ability for spectrum licences to be traded (and potentially leased).

The way in which these market mechanisms are applied to mobile spectrum (if they are applied at all) can vary. Indeed, the way the market mechanisms have been applied to mobile spectrum has changed over time, and this study considers whether further changes may be warranted in future. When assessing a particular market mechanism in this report, we have attempted to make clear (either explicitly or implicitly from the context) whether we are referring to the market mechanism as previously implemented at some point in the past (e.g. as originally envisaged in the Cave report), as currently implemented by Ofcom, or a possible refinement that could be implemented in the future.

C.2 List of acronyms

3GPP	Third Generation Partnership Project
AIP	Administered incentive pricing
ALF	Annual licence fee
ANACOM	Autoridade Nacional de Comunicações (Portuguese NRA)
AR/VR	Augmented reality/virtual reality
ARCEP	Autorité de régulation des communications électroniques, des postes et de la distribution de la presse (French NRA)
ARPU	Average revenue per user
BEM	Block edge mask
CMRA	Combinatorial multi-round ascending
CS	Circuit-switched

218 In its broadest sense, 'pricing' refers to the levying of any fees (other than those paid in an auction) on spectrum licences. This could include cost-based fees. AIP in its broadest sense refers to the setting of ALFs above administrative cost to reflect certain spectrum management objectives. As discussed in Section 5.3.1, AIP (in this broad sense) has applied to certain nationally licensed mobile spectrum since the late 1990s, but was not set to reflect 'full market value' until 2018 (though Ofcom began the process several years earlier). Unless otherwise specified, we use the terms pricing/AIP/ALF to refer to ALFs set at full market value.

CSFB	Circuit-switched fallback
DCMS	Department for Digital, Culture, Media and Sports
DL	Downlink
DSA	Dynamic spectrum access
EC	European Commission
ECC	EC's Electronic Communications Code
EU	European Union
FCC	Federal Communications Commission
FCFS	First come, first served
FDD	Frequency division duplex
FWA	Fixed-wireless access
GPRS/EDGE	General Packet Radio Service / Enhanced Data rates for Global Evolution
GSM	Global System for Mobile Communications
GSMA	GSM Association
HSPA	High-speed packet access
IP	Internet Protocol
IRR	Internal rate of return
ISP	Internet service provider
LAL	Local access licence
LTE	Long-term evolution
LTE-M	Long-term evolution machine type communication
MBB	Mobile broadband
MIMO	Multiple-input, multiple-output
MNO	Mobile network operator
MVNO	Mobile virtual network operator
NB-IoT	Narrowband-Internet of things
NRA	National regulatory authority
OTT	Over-the-top
PS	Packet-switched
PSSR	Public Sector Spectrum Release programme
PWN	Public wireless network
RA	Radiocommunications Agency
RAN	Radio access network
ROCE	Return on capital employed
SDL	Supplementary downlink
SMRA	Simultaneous multiple round auction
SMS	Short messaging service
SPF	Spectrum Policy Forum
SRN	Shared Rural Network
SRSP	Strategic Review of Spectrum Pricing
TDD	Time division duplex
UHF	Ultra high frequency
UKB	UK Broadband

UWB	Ultra-wideband
VoLTE	Voice over long-term evolution
WACC	Weighted average cost of capital
WRC	World Radiocommunication Conference
WT Act	Wireless Telegraphy Act 1998

Annex D Independent peer review team and findings

D.1 The independent peer review team

The independent peer review team consisted of the following four experts:

- William Webb (team leader)
- Simon Saunders
- Geoffrey Myers
- Stefan Zehle.

The peer review team was selected by the SPF for their extensive experience and independence. William Webb, Simon Saunders and Geoffrey Meyers have held director positions at Ofcom in the past and brought a spread of expertise to the review across economics, spectrum policy and technology. Stefan Zehle brought an extensive international mobile industry background.

D.2 The independent peer review findings

D.2.1 Overview

The short paper sets out the views of the peer review team on the Analysys Mason report about the market mechanisms put forward in the Cave Report in 2002. We firstly discuss the summary table and then the body of the report.

D.2.2 The summary table

The report starts with a summary table, reproduced below, which summarises the views from Analysys Mason.

Figure D.1: Summary of key conclusions [Source: Analysys Mason, 2022]

Question		Trading	Auctions	Pricing
Does the basic philosophy articulated in the Cave report still support use of a market mechanism of this form?		Yes	Yes	No
Is the market mechanism approach and current implementation of that approach optimal in terms of both promoting spectrum efficiency and avoiding undue problems/risks?		No	No	No
Are there possible alternative options that might lead to better outcomes, in relation to …	… the market mechanism approach?	No	No	Yes
	… the way the market mechanism approach is currently implemented?	Yes	Yes	Yes

While such "yes/no" answers can clearly be a blunt way to look at complex issues we agree with the entries in the table. In particular:

- Concerning the top row we agree that trading and auctions still have a role to play, but that the spectrum management benefits of pricing (as applied to cellular) are far less clear.
- Concerning the second row we agree that across all of the market tools that the current approaches are not optimal.
- The third row is divided into two parts. The top of these is broadly just the inverse of the top row of the table. The bottom row sets out that there are alternative ways to implement the market approach that might lead to better outcomes. We agree with this.

Our view is that, in general, the part of the report that leads to the conclusions in the first two rows has highlighted the key evidence and developments over the period since the Cave report and drawn broadly appropriate conclusions as to the role of market mechanisms such as ALFs and trading.

Hence, in summary, the table sets out a conclusion that while trading and auctions have a role in current and future spectrum management, current approaches are sub-optimal and that there are better alternatives. We agree.

D.2.3 The case presented in the report for change

While we agree with the table, we think that the report is weak in making the case for the entries in the last two rows. Any case for change relating to spectrum management needs to be forwards looking. While the report has been enhanced to provide more discussion of the future than earlier versions, there is very little in the way of opinion or recommendations. Instead, the report simply notes that there are emerging tools and that they may, or may not, be useful in the future.

We accept that the report was not intended to provide a detailed view of the future, and while we believe more could have been done, we recommend that another piece of work be undertaken, focused entirely on the optimal spectrum management tools for the coming decades. In such a report we would like to see one or both of the following approaches adopted.

Scenarios

We would strongly recommend a set of scenarios bringing out the implications and tools needed. For example, one scenario might be that mobile traffic continues to grow at 40%/year but that the new spectrum available in low and mid band is relatively minimal. Under this scenario a substantial increase in small cells will be needed, the majority of which will be indoors. This will require access to shared spectrum to enable neutral-host indoor deployment or for self-deployment by building owners alongside Wi-Fi. A very different spectrum access model will be needed, focused on database approval or similar (and not any of the existing tools) with different pricing models such as costs per transactions.

Another scenario might be merger across multiple operators and the emergence of wholesale network providers. Here, all of the spectrum might move to a single entity so auctions and trading will be of little value and other approaches needed to ensure efficient use. Or it could make way for the emergence of new entrant operators but with a different niche operating model with very different needs for spectrum.

A third scenario might be that entities such as the MoD open all their spectrum up for shared access, leading to an environment where large amounts of spectrum is sharable and with varying degree of rights that can be bought and traded. Use of artificial intelligence and other approaches might then lead to an effective spectrum abundance where approaches such as auctions are no longer needed and other ways to apply economic incentives such as spot and futures markets might be more appropriate.

Other scenarios can be envisaged and should be explored.

Where each tool is useful

An alternative approach is to take each of the future tools mentioned, such as depreciating licenses, foothold and incentive auctions, DSA, etc and for each to set out the situations in which the tool would be useful. There could then be a comment on the likelihood of these situations and hence the likely importance of the tool in the future. In doing so, it would be interesting for the report to assess the viability and usefulness of possible future market-based approaches to provide MNOs and other licensees with incentives to offer their spectrum for use by others. The incentive could be receiving revenue from leasing, or even via a much richer set of markets, including contracts of varying duration, spot and futures markets (as exist for more easily traded commodities).

Recommendations

We would like to see clear recommendations for DCMS, Ofcom and others for forward looking tools and strategies. For example, what should Ofcom be doing in regard to DSA now, in 2–5 years' time and longer term? Where are there deficiencies that should be addressed or uncertainties where options would be valuable? What should be done to ensure those options are available in appropriate timescales?

Evidence base

The evidence base used to arrive at the conclusions in the current report is limited, with discussion held only with a narrow set of stakeholders and almost no use of numerical data. In any future report we would like to see at least some consideration of the needs of a wider range of stakeholders including potential new entrants, and some consideration of evidence from other markets interpreted in the UK context.

Allocation decisions

The scope of the current report is limited to the role of market mechanisms after a decision to award on a licensed basis for mobile use has been made. We'd like to see a future report consider how emerging and novel market mechanisms might be used to address the balance of use of spectrum where there is a disparity of user types with an interest in the spectrum, including conventional national operators, private and local operators and short-range applications. These are inevitable as shared spectrum becomes more common. For example. the current report references Ofcom's decision to use a mixed model in the forthcoming 26GHz award, but does not consider whether the design is in any sense optimal or what framework to use for the design of comparable awards in the future.

D.2.4 The way ahead

We suggest that the Analysys Mason report be seen as having made the case for change through its assessment of the role of market mechanism over the last 20 years. However, it has not clearly set out the recommended alternatives nor fully assessed the situations under which other alternatives tools would best be used. We recommend a further study concentrating on which of the alternative approaches listed in the Analysys Mason report should be preferred in future.

D.2.5 Detailed comments

We have refrained from providing a long list of detailed comments on the text of the report. However, we would call out the following

Pricing (ALFs) and coverage commitments:

- The current approach to ALFs includes an impact assessment, it would be worth noting that this approach remains an option as long as the impact assessment considers the issues discussed in the Analysys Mason report.
- ALFs and obligations to improve networks (such as coverage obligations) are logically separate items. Rather than barter ALFs against obligations it would be beneficial to set up the discussion of commitments for improved coverage or quality starting from their desirability and the best way to procure them.