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Opportunities for dynamic or adaptive approaches to managing spectrum in the UK

A discussion paper

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Contents

Section

Annexes to this paper are available as a separate document on Ofcom's website.

1. Overview

Enabling existing spectrum users to grow and innovate while allowing new services to emerge is an important objective for Ofcom. Our Spectrum Management Strategy emphasised the importance of sharing spectrum, and supporting different users – ranging from consumer mobile services to specialised industrial applications – by enabling greater flexibility in spectrum use.

In this document we explore the opportunities and challenges associated with applying flexible, increasingly time-based spectrum management approaches in the UK. Such approaches are generally referred to as forms of Dynamic Spectrum Access (DSA) and promise gains in the efficiency of spectrum use, by allowing users to share the same spectrum by managing the times and places at which they transmit.

Key findings for the future

We have considered the need for more flexible spectrum management solutions in response to growing demand for spectrum, and in light of technological developments. We consider that:

- **More automation and better data can deliver significant gains.** Ofcom is already taking action to automate more of our licensing process and collect better usage data. This can lay a foundation for more advanced sharing, providing the means to quickly adjust user assignments where usage gaps are identified. More standardised usage data across vendor equipment could increase the opportunities these processes can support.
- **Dynamic access may best meet user needs where enabled as a 'top-up' to more guaranteed capacity.** Predictable spectrum access is important for users seeking to meet quality of service requirements**.** Consequently, dynamic sharing, where spectrum supply comes and goes, may be most beneficial where the user has access to other spectrum, so that access **'adapts'** over time, and/or the dynamic sharing is associated with a level of **'guarantee'** for the times and bandwidths available.
- **The equipment ecosystem needs to support greater flexibility.** While significant progress has been made developing the technical foundations for more dynamic sharing, further steps are required to increase the availability and reduce the costs (including upfront investment and operational costs) of more frequency agile and flexible equipment, which could bridge the gap from costly and bespoke solutions to something with broader application.
- **A blueprint for more open interfaces between devices and spectrum management databases could open new opportunities.** There may be benefits to enabling a more standardised form of access between an intelligent spectrum controller or database, and certain equipment. This would allow future spectrum management decisions to be informed by actual usage and flexed over time, without imposing bespoke band-by-band burdens on users and regulators.
- **There is potential for such dynamic and 'adaptive' approaches to play a part in addressing future spectrum management challenges**, including spectrum access for wireless broadband evolution to 6G, and supporting a range of users with growing spectrum demands. We will look to our Spectrum Sandbox programme as an opportunity to further explore this with industry and academia over the coming months.

2. Introduction

Why Ofcom is undertaking this work

2.1 Wireless communication plays an ever more significant role across many sectors of the economy, delivering our news, connecting us to friends and family, automating industrial processes, supporting public services and monitoring the natural environment. Radio spectrum (the 'airwaves' that enable wireless technology) is a limited resource crucial to delivering these services, and Ofcom has the job of ensuring it is used in the best interests of all in the UK.

2.2 Ofcom's principal duty with regards to spectrum management is to ensure that spectrum is being managed in the most efficient way. As demand for spectrum continues to increase, Ofcom is committed to exploring options that would enable greater sharing of this scarce resource, which we identified as an area of increased focus in our 2021 Spectrum Management Strategy.

2.3 More flexible and dynamic equipment is increasingly being incorporated across devices and networks, from more adaptable radios and antennas to the adoption of Dynamic Spectrum Sharing (DSS) between 4G and 5G technologies within mobile networks.[1] Consequently, the last decade has seen a variety of different regulatory solutions developed to take advantage of this, highlighting the potential power of combining new technologies with flexible spectrum management tools.

2.4 The TV White Spaces framework launched in the UK and across several other countries, and the opening up of the CBRS band in the United States, have already demonstrated the potential of more dynamic approaches, targeted at specific problems in particular bands.[2]

2.5 Ofcom recognises the potential of flexible and dynamic access to spectrum to enable innovation and growth, and is keen to help shape the ongoing debate over whether similar approaches can be applied more broadly, by working with industry and academia on how this might be brought to benefit UK citizens and consumers.

2.6 We are already working on the automation of our licensing processes, to provide a better user experience and significantly reduce the time taken to access spectrum. We are keen to stimulate the development of spectrum sandboxes, working collaboratively with stakeholders, to collect more information on spectrum usage to inform our policies. Additionally, having looked at the current dynamic solutions being deployed to respond to specific situations, we want to highlight to industry the potential benefits that could flow from more band-agnostic and open solutions, which could reduce complexity, cost and

[1] DSS seeks to ensure the best balance of spectrum resource blocks available for each technology at a given moment in time, based on user needs.

[2] Ofcom's TV White Spaces (TVWS) programme coordinated a secondary user's (PMSE) spectrum access around a primary user (Digital Terrestrial TV), and enabled access for other parties where both these users were absent. The USA adopted a tiered and dynamic approach in the 3550-3700 MHz band (the Citizens Broadband Radio Service, or CBRS) to enable mobile broadband and other uses alongside incumbent military systems and civilian satellite earth stations.

implementation time. This should, over time, facilitate greater adoption of more dynamic solutions that could help meet growing demand for spectrum.

Principles of dynamic spectrum sharing

2.7 Spectrum sharing is not new, and our 2016 framework for spectrum sharing sets out the framework for our current policies. Our aim is to ensure that we support innovation and growth by making the most of any opportunities presented by technology developments and differences in actual spectrum usage on the ground.

2.8 While there is a wide variety of subtly different approaches to spectrum sharing, these solutions can be characterised as covering four broad categories:

a) **geographic separation:** where users who are far enough apart can use the same spectrum without causing harmful interference to each other;

b) **time-based (interweave):** where different users access the same channel in the same area but at different times (potentially separated by large chunks of time, or very narrow differences in duty cycle);

c) **underlay:** where differences in operating powers and bandwidths are used to enable the sharing systems to effectively separate the wanted signal from the unwanted signal (such as in ultra-wideband technologies); and

d) **collaborative:** where sharing systems exchange 'side information' to differentiate signals, and potentially dynamically adapt their operating conditions to ensure that while service levels for the sharers may vary, a net benefit is maintained.[3] [4]

2.9 Geographic sharing underpins the coexistence of many users today, including fixed links, PMSE and business radio, as well as users of our Shared Access framework, which we introduced in 2019 to enable localised access to mobile spectrum, shared on a first come, first served basis.[5]

2.10 **Dynamic approaches are more typically built around time-based sharing**, although they may also involve a geographic dimension. A common example of this approach today is the 'listen before talk' device-led protocol in Wi-Fi, where the device 'listens' for transmissions and only transmits if it is unlikely to cause significant interference because the relevant channel is quiet.[6] Dynamic access can also be managed via a database, where devices query a database which stores information on the locations and operating times of other users and determines if a new user device can access the spectrum.

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[3] Side information includes knowledge of the primary users' codebooks and uses advanced coding and signal processing to mitigate interference, potentially including the training of transmission slots based on machine learning between users.

[4] Collaborative solutions outside of individual networks remain largely a question of research – we provide some further detail on the principles of this approach in Annex A2.

[5] Ofcom launched our Shared Access Framework in 2019, to meet growing demand from a range of new stakeholders to access spectrum capable of supporting mobile technology. Details of our approach, and how to apply, can be found in our Shared Access licence guidance document.

[6] The channel may be quiet either because it is not being used in the vicinity or because the use is sufficiently far away and at a low enough signal level that any interference between the different devices should not significantly affect them.

2.11 Such dynamic approaches usually rely on an analysis of information on the radio environment (e.g., how, where and when the spectrum is being used) to allow additional users to access gaps in existing users' activity; and solutions for moving users in the event of clashes.[7] We use the term Dynamic Spectrum Access, or 'DSA', as an umbrella for these types of approach.[8]

2.12 The benefits of these approaches depend on whether and how the demands of users can be separated in time and/or geography without unduly affecting the quality of those users' services. To date, such approaches have often involved relatively bespoke solutions to the specific problems faced. Regulatory solutions therefore need to account for the potential additional costs involved in deploying more intelligent solutions, and any resulting impacts on spectrum usage.

2.13 In this document we explore the opportunities associated with the application of a DSA-style framework, as follows:

a) We begin Section 3 by introducing some of the different dynamic spectrum management options, highlighting the different problems they seek to solve, and how these options can impact users.

b) We then consider the kinds of spectrum demand that might be met by such solutions, and how technology could best support and enable that demand in the years ahead.

c) We illustrate these opportunities through two case studies where 'top-up' access to additional spectrum could be facilitated by better data and more flexible equipment, while also recognising scenarios where greater certainty of access is required.

d) We conclude in Section 4 by highlighting the benefits of ongoing work on automation and improved data capture, pointing to the potential gains from a more flexible, band-agnostic user equipment ecosystem, and the opportunity our 'Spectrum Sandboxes' project provides to explore this in the coming months.

[7] These gaps can cover minutes, hours, or days, but tend to be less predictable under a fully DSA regime than slower and more predictable variations that also constitute time-based sharing, but can be managed in other ways.
[8] In addition to the TVWS programme and CBRS, other examples include Dynamic Frequency Selection in certain types of licence exempt equipment, and proposals (considered by the USA and Canada among others) for an Automated Frequency Coordination (AFC) regime to manage coexistence between Wi-Fi users and existing fixed links in the 6 GHz band, and so enable Wi-Fi to operate at higher powers where this will not have an interference impact.

3. Aspects of dynamic spectrum access and associated opportunities

Automation is a building block for future flexibility

3.1 At its core, a Dynamic Spectrum Access regime may be expected to have two main characteristics:

a) **Automated allocation** of spectrum resources to individual users, and;

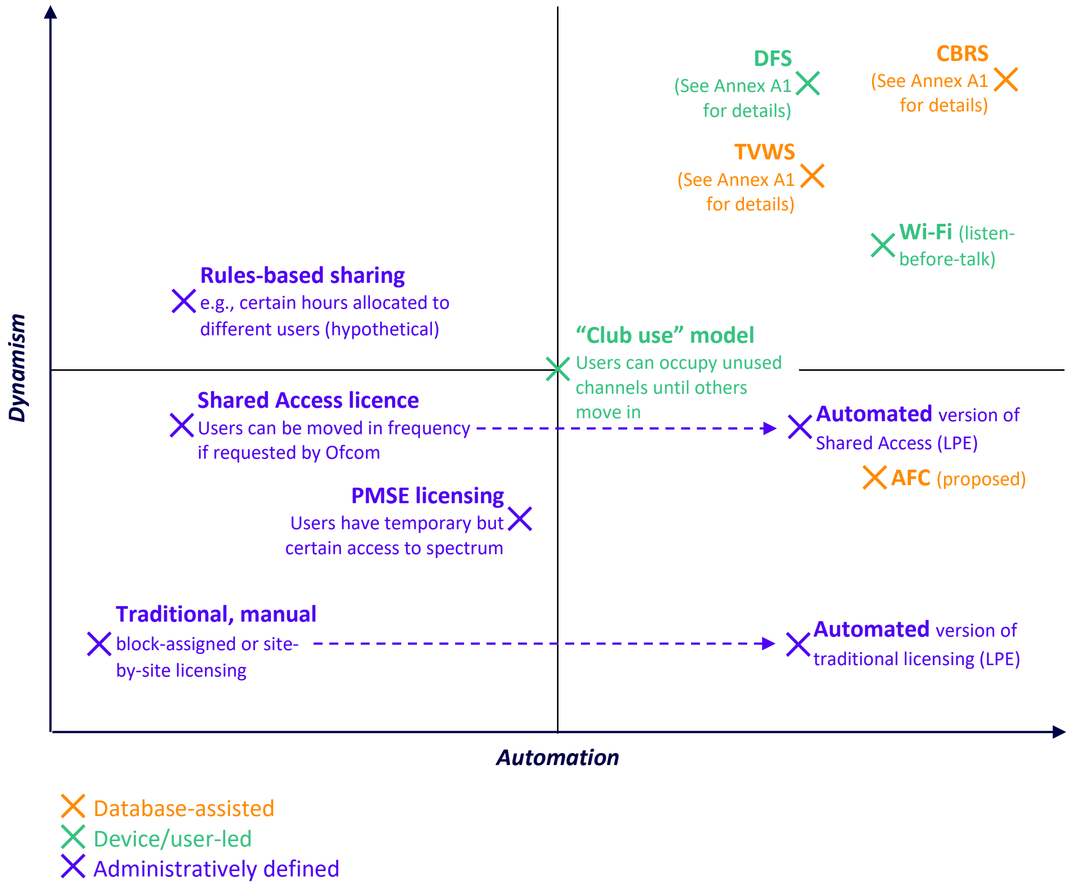
b) **Time-based and dynamic allocation** of spectrum between different users.

3.2 Automation is a very valuable tool, and a foundation for more complex and advanced sharing. Furthering automation in the licensing process can support faster turnaround times for licence applications, require less human involvement at both ends of the process, and potentially open space for device-to-device interfaces where a wireless system automatically secures the licence it requires to operate. This can help support more flexible changes to assignments in the future.

3.3 The most common sharing solutions today are based on more traditional geographic sharing, and have tended to have limited dynamic components and historically less need for end-to-end automation. However, automation is not in itself the same thing as DSA, but rather a tool that may be used in more static systems, which also opens up options for very dynamic adjustments to time-based spectrum allocations. Some more basic time-based sharing systems could also be supported without automation, in more manual and predictable ways. (For example, a simple rules-based system could manage time-based sharing where one user transmits during the day and another during the night).

3.4 We illustrate this below by comparing the levels of automation and dynamic access in a range of sharing scenarios, covering device-led, database-assisted and administratively defined sharing solutions. We provide further detail on key examples featuring the greatest combinations of automation and dynamism (CBRS, TVWS, and DFS) as well as the most recent developments (in the form of AFC) from paragraph 3.15.

Figure 3.1: Illustrative schema of variations in dynamism and automation in existing systems



Source: Ofcom

3.5 There is a broad consensus, from industry stakeholders, that more automated licensing processes would be of great benefit to users, and Ofcom is taking steps to address this. We are currently updating our spectrum licensing software to a unified single system. This Licensing Platform Evolution (LPE) programme aims to provide a much greater degree of automation in the licensing process. This work is being delivered in phases, with some of our non-coordinated and Shared Access licences moving to the new platform in early 2024.[9]

3.6 The further development of these licensing tools in the coming years has the potential to provide a platform for, and act as a springboard to, more dynamic spectrum management solutions. The greater the capability embedded in these tools to automate usage data collection and enact rapid changes in user assignments (including through direct device communication) the more they can support and enable new dynamic sharing solutions in the future, as more device-level data becomes available.

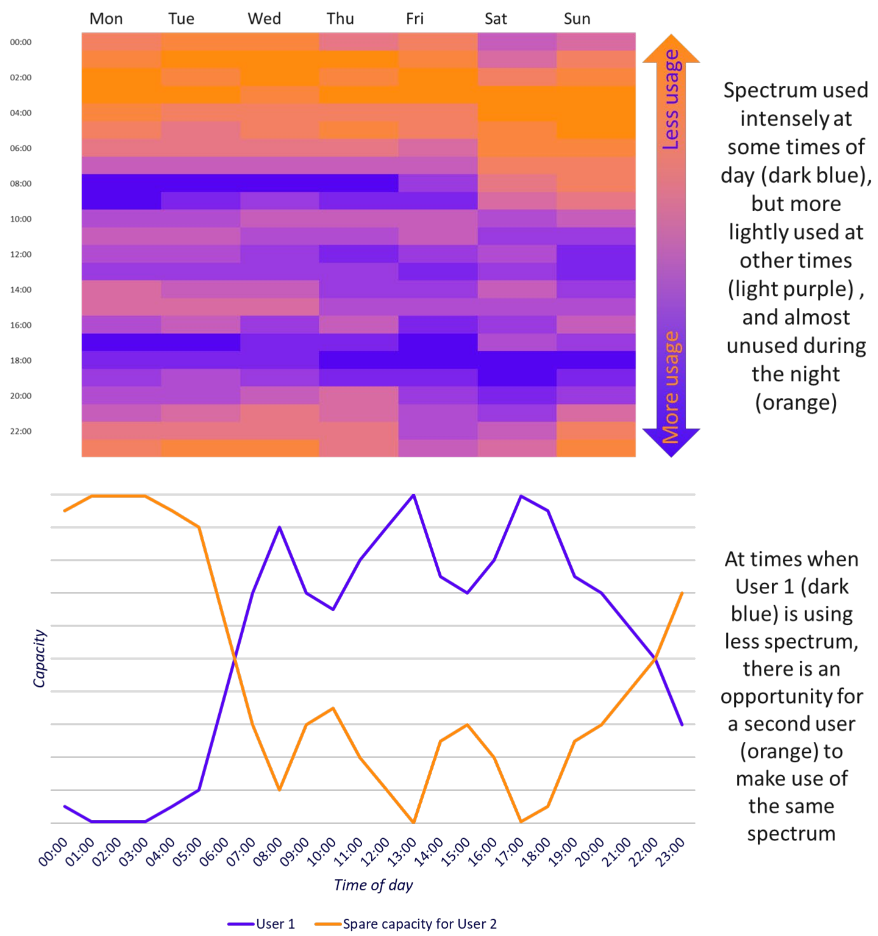
[9] We set out these plans, and potential benefits for Shared Access in more detail in our Shared Access update publication.

Increasing levels of dynamic spectrum access open new sharing opportunities, but come with some trade-offs

3.7 Increasingly dynamic, time-based approaches to spectrum access, supported by automation, can target more granular gaps in spectrum usage and offer new sharing opportunities.

3.8 An overview of the principles underpinning this are set out in Figure 3.2 below. The spectrum usage waterfall (top) highlights how certain spectrum frequencies may be more lightly used at different times, opening up gaps for new users as shown in the graph (bottom).

Figure 3.2: Illustration of spectrum occupancy gaps (top) and their time-based exploitation (bottom)



Source: Ofcom

3.9 The result can be a greater efficiency in spectrum use as more users are able to make the most of this scarce resource. However, especially for the most dynamic regimes – where the ‘gaps’ in usage may change quite regularly and sometimes at short notice – this can increase the chance of clashes between services, or short notice changes in access to the spectrum, with potential knock-on effects for the overall quality of service (QoS) levels a user would retain.

3.10 These knock-on effects typically fall into one of the four categories below:

a) a user could see the **quality of their access reduced incrementally**, for example if it was necessary to accept interference from another sharer in the band;

b) a user could see a **reduction in available bandwidth**, and may be required to adjust operational frequencies as additional users appear;

c) a user could **completely lose their spectrum access** if a user who is deemed more important emerges in their area; or

d) a user might **temporarily lose access to some of their spectrum**, but retain more guaranteed access elsewhere (such access would be a **'top-up'** to pre-existing or more guaranteed capacity).

3.11 While none of these outcomes are necessarily desirable on their own terms, they may be justified where they are solving a particular problem or addressing an access challenge that cannot otherwise be easily overcome (e.g., an existing user is unable to move).[10]

3.12 Accessing more information on spectrum usage, and the radio environment of an operating system, can help manage the impact of these knock-on effects, by establishing the scale of opportunity in a given band or location, and so increasing certainty for users. In the most advanced concepts of dynamic sharing, it is often proposed that this information could be accessed and acted on at the device level in real time. However, while narrow implementations of device-level sensing do exist, there remain barriers to the development of more independent 'Cognitive Radio' devices (which we describe further in Annex A2) and a database is often required to store and analyse such usage information.

Different dynamic approaches have been developed to enable coexistence between users and manage knock-on effects

3.13 A number of approaches have been implemented to meet additional demand and increase the efficient use of the spectrum, while managing the potential for additional coexistence challenges and knock-on effects on spectrum access.

3.14 Often these challenges require some kind of hierarchy to be established between the users, so that a user lower in the hierarchy may be periodically required to switch off/move to another frequency/reduce their available bandwidth. This is done to protect users higher up in the hierarchy (for example if they relate to public safety). Such a hierarchy may not be required if there is expected to be sufficient spectrum for all users (because the

[10] In theory, dynamic access could also enable a more certain outcome for users, where the specific frequencies offered to the user change but the total bandwidth available is dynamically maintained across a jigsaw of different bands and time slots, which could be described as 'multi-band guaranteed access'. We are not aware of any practical application of this approach today, but note that this could open up new opportunities for sharing, and mitigate challenges for users, if technical developments supported it in the future.

number of users, or the types of user device, has been limited in some way) or where it is considered reasonable to tolerate the risk of interference and/or potential deterioration in service quality/capacity offered.

3.15 We provide a brief overview below of some of these different approaches, implemented over the last decade, to highlight how they have enabled access for new users with differing elements of dynamism and automation, often with new or bespoke requirements. We provide more detail on currently active examples in Annex A1.

a) **Dynamic Frequency Selection (DFS):** *This is a 'device-led' approach found in Wi-Fi and other systems, where individual devices make independent spectrum access decisions (within a narrow framework) to protect existing users.*

As noted above, Wi-Fi is an example of existing time-based sharing that works on a relatively dynamic basis by using a listen-before-talk politeness protocol to avoid channels occupied by nearby users. In certain bands and environments (e.g., outdoor use), this has been supplemented with the additional requirement for Dynamic Frequency Selection (DFS). Here the user equipment (often a Wi-Fi router) performs an additional check for the presence of any radar system on the same channel. If a radar is detected, the Wi-Fi router must seek a new channel elsewhere (which can take some time), and so experiences a **reduction in available bandwidth**. However, the precise performance of this test can vary with different firmware upgrades and can sometimes act as a 'false trigger', meaning that while the existing radar user is detected, the mechanism does not always secure the most efficient spectrum use.

b) **TV White Spaces (TVWS)**: *This is a priority-based (hierarchical) approach, with automated dynamic access controlled via databases operating across the range of 470-694 MHz.*

A database (or databases) approved by Ofcom protects Digital Terrestrial TV (DTT) broadcast reception and Programme-Making and Special Events (PMSE) assignments as first-tier and second-tier users respectively. PMSE users already operate in the channels not used by DTT, and must give way to changes in DTT use (DTT network reconfigurations do occur but are typically infrequent). White Space Devices (WSDs) on the third tier may access channels that the database calculates are unused by either DTT or PMSE. However, if DTT or PMSE services require those previously clear channels, WSDs must give way by finding another unused channel, or if none can be found, by ceasing transmission (effectively **losing spectrum access**).

c) **Citizens Broadband Radio Service (CBRS)**: *This is another priority-based (hierarchical) approach, with multiple databases controlling access, informed by a network of sensors.*

The USA's Citizens Broadband Radio Service (CBRS) operates in the 3550-3700 MHz range, using a network of sensors and database controllers to facilitate the coexistence of mobile and other wireless systems alongside incumbent naval radar systems and civilian satellite earth stations. Pre-existing users are protected as top tier users. Tier 2 is made up of Priority Access Licences (PALs) awarded at auction, whose users can expect **limited interruptions** to service from the top tier user. Tier 3 is available for General Authorised Access (GAA), where users can connect to a CBRS database to secure access quickly, but without a licence and without formal protection levels. This means that the QoS of GAA users is at risk of being **reduced incrementally** if other users move in over time.

d) **Automatic Frequency Coordination (AFC):** *This approach protects existing users by requiring devices to register with a database before operating at higher powers.*

In 2020, the US Federal Communications Commission (FCC) indicated that it would make available parts of the 6 GHz band for low power, indoor use for Wi-Fi type applications. It also indicated that a higher operating power could be enabled for devices under the control of an Automated Frequency Coordination (AFC) system. This system would perform regular checks against a database of assignments from existing users (in this case point-to-point links) to ensure higher powers would not cause interference. Should a link be detected, the quality of the Wi-Fi routers' access would **reduce incrementally**, as operations would have to remain at low power. AFC databases have now been developed by a number of manufacturers, and capabilities are being added to chipsets of many Wi-Fi routers to facilitate this interaction.

3.16 As can be seen, some of these examples place more weight on 'device-led' decision making, and some rely more on databases. In some cases, this can be managed by a single database system (e.g., TVWS in its current form), whereas others (e.g., CBRS) make use of multiple competing databases. All approaches feature different levels of automation, as illustrated above in Figure 3.1. However, all examples involve aspects of time-based sharing that can be subject to variation and change, and consequently have potential impacts on the certainty of user access, or the QoS levels a user can expect.

Identifying use cases that would benefit from dynamic spectrum sharing

3.17 The increased take-up of more dynamic approaches is likely to be founded predominantly on time-based opportunities, given there is a strong degree of geographic overlap in the areas of growing demand for spectrum around population centres. These opportunities could include use cases with more time-variable needs for spectrum access (which might be coordinated with other users), or services able to tolerate fluctuations in service quality (who might access gaps more opportunistically).

Services whose times of operation change may not need continuous spectrum access, but may need QoS guarantees

3.18 Spectrum users whose times of operation change or who have highly variable traffic demand over time may be suited to sharing with others in the time dimension, although requirements may vary case by case, and hierarchical protection may be needed.

3.19 For some existing users, these changes may be quite distinct and predictable. For example, radioastronomy is a QoS-sensitive user that can require significant protection from interference, but only around the frequencies that the radio telescope is monitoring at a given time. Because different frequency bands will be monitored at different times (and with different focuses sometimes lasting for weeks or months at a time), these protections might not be needed all the time, potentially allowing new users to operate in the time gaps.

3.20 Other existing users may have more complex changes in use, that are more difficult to predict and manage. One such scenario might be military users, who require access to significant amounts of spectrum but often only use it in certain locations at certain points in time (as we discuss further from paragraph 3.39 below). In both such cases, it is likely that clear agreements would be required on the access rights of new users, and what would happen in the event of a clash between services, to ensure access levels of existing users were protected.

3.21 At first glance, one might consider that the greatest opportunities for these kinds of sporadic users to dynamically share with other users would be to share with those whose spectrum needs are also sporadic or time-limited. Examples of this could include PMSE, temporary connectivity to support pop-up e-health interventions, or spectrum access to support localised emergency service activity. It could also include users who are ‘in motion’ (e.g., drones or trains) and whose spectrum requirements in any particular location would be time-limited, even if their usage as a whole was more ongoing.

3.22 We recognise the potential for growth in such use cases that could benefit from sporadically accessing gaps in spectrum use for limited periods of time. However, we also recognise many of these types of use may themselves need some guarantee of quality of service at the point of need, which may make dynamic sharing more challenging if there is a chance of another user being present at the same time and location.

QoS-tolerant users may be able to lose some spectrum access, especially where this is a ‘top-up’

3.23 Users who can tolerate variations in QoS may be the most suited to sharing alongside some of the users mentioned above, whose own operating requirements are less flexible. We consider that development and growth of such use cases could be a significant driver towards more time-based allocation in the future.

3.24 This ‘tolerance’ for time-based sharing is likely to come in two main forms:

a) **Non-time-critical:** Some services require access to spectrum, but not in a time-critical way, so that they could wait to access spectrum around gaps in existing use. This might include monitoring functions for some aspects of smart agriculture, or periodic reporting of supply levels (including in industrial and utilities type applications).[11]

b) **Flexible bandwidth**: we have identified potential opportunities to support services which are typically quite demanding in and of themselves, but may be able to manage some reductions in the bandwidth available to them for limited periods of time. This could particularly be the case for a user with a range of spectrum bands to fall back on, as well as changes in their peak network demands. For example, this might include mobile or fixed wireless broadband networks, or the provision of neutral host services supporting mobile networks, accessing additional spectrum dynamically on a **'top-up'** basis. It might also apply where some new spectrum is made available as a more guaranteed anchor, supplemented with additional spectrum that was dynamically available on top, which could be characterised as a **'flexible guarantee'**.

The 'top-up' opportunity and Adaptive Spectrum Allocation

3.25 We see potential in the introduction of a 'top-up' model, where new spectrum users can access additional spectrum dynamically, but always have a range of other bands to fall back to, when the existing spectrum users might need access to the band in question. **We consider this 'top-up' scenario, and the prospect of a 'flexible guarantee' alongside it as examples of an Adaptive Spectrum Allocation ('ASA') regime**, where access adapts over time, rather than risking it completely disappearing at certain points.

3.26 **We will consider the potential of such dynamic or adaptive solutions in our future spectrum management decisions, as it could be applicable to a variety of spectrum users, including enabling wireless broadband growth to 6G**, where we believe more sophisticated sharing may be required to manage both existing and new users.

3.27 We recognise the need for new spectrum users to have some certainty of the minimum quality of service they can offer. We also recognise that even for 'top-up' access there may still be limits to users' ability to absorb very dynamic changes in spectrum supply. The extent of these users' alternative spectrum holdings, and the times at which access changes occur, may impact their ability to manage changes to the QoS they can offer.

3.28 The value of this opportunity may be enhanced (and more likely to justify the costs likely to be involved in more bespoke solutions) where the 'top-up' access is likely to be available at times of peak network loading (whether in the form of countrywide network busy hours, or on a more localised basis). Consequently, and as we expand upon below, better data on existing usage will be key to unlocking such opportunities.

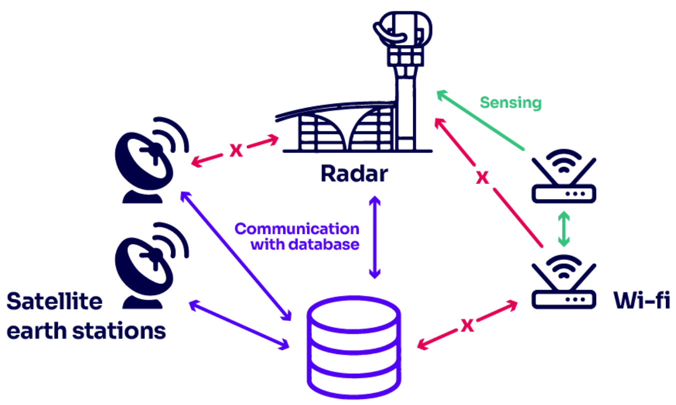
[11] We note that while these opportunities have the potential to grow, it may be possible to accommodate some of them within existing frameworks. For instance, much of this IoT-type traffic may continue to be carried over mobile networks and (via Wi-Fi) the fixed network, and fitted around quieter network times.

Cost reduction, equipment flexibility and usage data are enablers of more dynamic spectrum sharing

3.29 In recent years, significant progress has been made developing the technical foundations for more dynamic sharing. However, further advancements may be needed to make it more straightforward to open opportunities for authorising more users. We cover the potential for technology to support more dynamic sharing solutions below, and provide further details on technical challenges for the most advanced scenarios in Annex A2.

3.30 In many cases the major challenges are not fundamental technical limits. Rather, the more widespread availability and adoption of modern equipment (supported by reductions in cost over time), and the more consistent integration of new tools across different ecosystems, could help bring the largest opportunities within reach. We recognise that many leading-edge opportunities may be most readily developed and perfected within a single network (as we have already seen with the implementation of DSS), where compatible ecosystems can be tightly defined and managed. However, the additional complexity of information exchange in a cross-service environment, where equipment may not speak the same language or interact with a database in the same ways, is currently a limiting factor to enabling more dynamic sharing.

Figure 3.3: Illustration of a hypothetical cross-service environment, with some users exchanging data through a database, some through device sensing, and communication barriers in between



In this diagram, some users are able to connect to a central coordinating database, while others detect nearby users through sensing. Here, in a hypothetical scenario, Wi-Fi routers can detect the presence of radar, but are unable to connect to the database, while satellite earth stations rely on the database to inform them of the radar's operations, as they cannot detect this through sensing.

Source: Ofcom

3.31 **We have identified three potentially important areas where we would like to see change** to help reduce long-run costs for users and make such new opportunities easier for all parties to implement:

a) **Equipment flexibility:** The increasing prevalence of Software Defined Radios (SDRs) and performance improvements in their selectivity, sensitivity and the bandwidth spanned may begin to lower cost barriers for more dynamic solutions across a range of spectrum bands. Adaptive antennas also promise potential improvements in systems' abilities to filter out unwanted signals, and to operate in a busier sharing environment.

However, there currently remain limits on the reconfigurability of equipment across wide spectrum ranges, and more flexible equipment can be more costly. These costs may extend beyond upfront capital investment in the latest technology to include additional ongoing costs such as deployment and validation of the more complex equipment and its maintenance over time. Even where this is manageable, technical developments will need to account for situations where the wider dynamic range enabled on receivers can increase the challenge of wanted signal detection (especially where other users operate in a band simultaneously). Consequently, continued developments in equipment flexibility are likely to enhance future opportunities.

b) **The collection of usage data:** 'Better information for better spectrum management' is one of our key areas of focus set out in our Spectrum Roadmap. We indicated in our Roadmap that, as a supplement to our existing spectrum monitoring work, we will explore the introduction of a proof-of-concept API (application programming interface) to allow users to log interference events and associated data.[12]

   Increasingly, it may be possible for the collection and sharing of this data to be automated at the device level, which could extend from more straightforward KPIs such as bandwidth used and utilization through to more complex channel quality and SINR analysis. All this data has potential value, but we acknowledge that usage data may be the most immediately accessible, and have the greatest near-term benefits. Where this is standardised, and so does not add significant costs or overheads, it could help to provide a reliable flow of data showing when and where spectrum might be available for new users and whether interference is being detected. This could have applications beyond dynamic sharing, but would particularly support the identification and exploitation of time-based sharing opportunities.[13] We are currently engaging with industry as part of our Spectrum Sandboxes project to identify scenarios in which this data might have the most benefit, and to develop processes for collecting data and applying learnings from it to spectrum management decisions.

c) **Open interfaces:** given some of the complexities of establishing common data collection and sharing protocols across different sets of equipment and user systems, we consider there may be value in seeking to establish a blueprint for a more common open interface that could connect user equipment (e.g., base stations) with an intelligent, band-agnostic database. This would make it simpler for spectrum managers, and users, to implement new dynamic spectrum sharing arrangements across a range of services without setting bespoke equipment standards, and enable more flexible changes to spectrum allocation over time. We do, however, recognise that developing such a capability will itself involve time and effort, and it would therefore be important to seek to define a solution that delivers this core functionality without additional

[12] Spectrum Roadmap, p. 45.
[13] We recognise that the provision of this data may in some cases raise important commercial issues or questions of data security, which will need to be addressed to fully exploit this approach.

complexities that are not useful. We set out a practical example of this opportunity in more detail from paragraph 3.45 below.

3.32 Economies of scale are likely to be important and may be reliant on large vendors recognising that such technologies can be beneficial both for their existing customers' efficiencies and also for the potential these tools have to support additional customer demand in the future.[14]

A range of other technical developments can support more advanced sharing alongside dynamic tools

3.33 Many of the developments and opportunities we have identified above can have a wider applicability and support more advanced sharing, but we consider them to be particularly relevant to enable more dynamic sharing.[15]

3.34 We are also keen to see progress and technical development in other areas that are likely to facilitate more efficient use of the spectrum via sharing, whether dynamic or not.

3.35 One area that is likely to be particularly important in almost any sharing approach is greater interference tolerance between users, which we emphasised as an important goal in our Spectrum Management Strategy.[16] This could be supported by improvements to receiver standards that facilitate coexistence between users at the edge of their operational areas. For example, two systems that have geographically separated target areas of operation can today still experience significant interference from each other, often largely as a result of signal 'overspill' from their target areas. In practice it can therefore be difficult to authorise such overlapping systems.

3.36 While Massive MIMO can support improvements in receiver selectivity, this is most applicable for frequencies above 3 GHz, and can increase deployment costs. Continued developments in receiver performance to increase resilience to interference from unwanted signals have the potential to significantly expand opportunities for sharing. This may be especially relevant when the receiver is part of a system sharing across a wide frequency range (e.g., under an adaptive allocation framework), as this increases the need to avoid blocking impacts from the signal of opposing systems within the same operational frequency range.

3.37 In the longer term, other technical developments may also emerge to support more advanced sharing approaches. This could include the development of processes that would enable the '**collaborative sharing**' techniques described at paragraph 2.8. We consider such techniques promising, but most likely to occur on an intra-network basis in the medium term. This is partly because of the complex exchange of user information required

[14] We note that even from this point, there is likely to be a lag in adoption across a full ecosystem, and legacy users may pose a barrier to fully exploiting such capabilities within a regulatory regime for the medium term.
[15] For example, better data is fundamental to facilitating more dynamic sharing, but could also support new opportunities for more basic time-based or geographic sharing.
[16] Supporting the UK's Wireless Future: Our spectrum management strategy for the 2020s, p. 24.

(which can take longer and lead to more unpredictable outcomes outside of a single network, and may expose commercially sensitive data). We explore this opportunity and associated challenges further in Annex A2.

Illustrating how these enablers can unlock new opportunities in adaptive sharing for 'top-up' users

3.38 To illustrate how potential use cases could combine with new technical developments to enable more dynamic re-allocation of spectrum in these 'top-up' scenarios, we identify two potential scenarios which can illustrate the benefits, and residual challenges:

a) **Better data and flexible equipment to unlock 'top up' opportunities for civil users (e.g., mobile broadband) to share with military spectrum use**.

b) **Better data and open interfaces to unlock new sharing opportunities between different services, where the spectrum supply is flexed based on collected data.**

Scenario A: Better data and flexible equipment to unlock 'top up' opportunities for mobile broadband sharing with military spectrum use

3.39 As noted above, the military uses large amounts of spectrum in the UK in a number of bands, but often at varying times and locations, often in a fairly pre-planned manner, and in ways that contrast with many other users (e.g., often more activity in rural areas than urban areas). Holding better data on such usage could enable Ofcom to make more efficient decisions in allocating spectrum between civil users, and potentially introduce time-based access alongside existing military use. This could provide benefit for a range of spectrum users with growing demands who could access this capacity on a 'top up' basis, one example of which could be mobile broadband.[17]

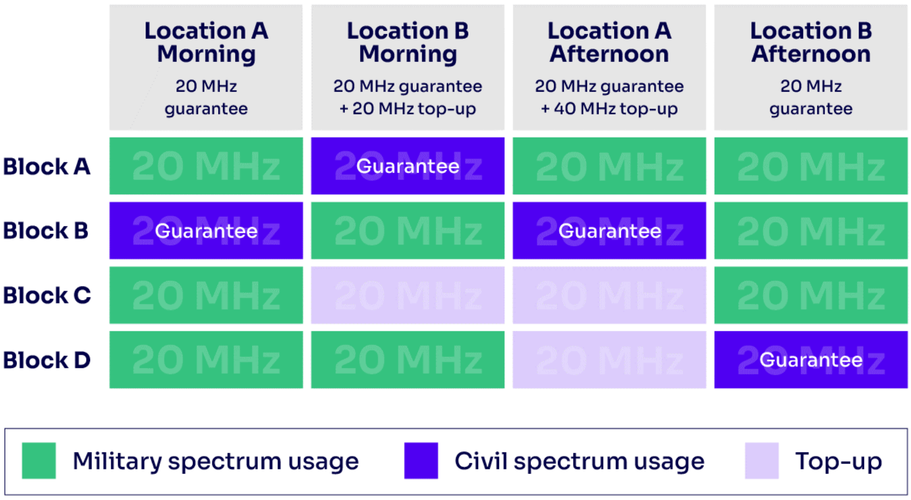
3.40 More simple time-based sharing could resemble an extension of the geographic sharing that already occurs today between the MOD and other users, with a fairly static set of time-based assumptions and fixed access rules (e.g., a limited list of areas and times where military use was not expected).

3.41 However, a more dynamic, database-managed approach could provide some additional benefits. In particular it could facilitate quicker and more granular decision-making on where spectrum is available, or where both existing and new user needs should be protected. More advanced approaches could take account of a more variable stack of differences in planned military use – so unlocking more access opportunities – and respond to relatively dynamic changes in that plan. While this could increase the uncertainty for an incoming user, an intelligent database may be able to manage these fluctuations and enable the incoming user to receive a larger guaranteed amount of spectrum (potentially

[17] We note that the UK Ministry of Defence (MOD) has expressed interest in enabling further civil access to spectrum it uses by means of dynamic and database-driven solutions.

made up from different chunks within a band, or across multiple bands), which might support a ‘**flexible guarantee**’ approach, as illustrated in Figure 3.4 below.

Figure 3.4: Illustration of database provisioned flexible guarantee, combined with additional opportunistic spectrum supply



This diagram provides a simplified illustration of how a database might manage differences in military spectrum use in different locations to safeguard a ‘guarantee’ of 20 MHz for a new civil user, even as this alternates across different frequency blocks. Additional bandwidth is then provided where it is available, while ensuring military access continues where it is needed.

Source: Ofcom

3.42 As sharing becomes more complex and granular, it becomes important that the existing user has robust and regular processes for providing updated information to the database on its usage patterns.[18] We consider that in this scenario, the most likely mechanisms for this would still involve a degree of pre-planned assumptions, informed by desk-based calculations, which could be updated at intervals (e.g., weekly or monthly).[19]

3.43 Given that it is in the nature of military uses that they change over time, there may be limits to how robust and enduring this ‘top up’ access and any associated ‘flexible guarantee’ could be. Any regime would need to establish the clearest ground rules possible on the terms of access and any potential for change over time, to provide certainty for both existing and new users. One option we think could merit further exploration is for this access to be associated with a confidence level, for example a commitment that the minimum availability will be maintained for 90% of the time and 90% of locations.

3.44 Today, progress towards unlocking such opportunities largely rests on the willingness of potential incomers to invest in operating in such an ecosystem on a fairly bespoke basis

[18] For example, new systems could be developed that must operate in the shared frequencies. Similarly, existing military systems could have to move to a specific area at short notice in an emergency, or operate more often and with more bandwidth.
[19] Other approaches, such as more device-led sensing, are possible, but may significantly increase operating costs.

(alongside willingness from the existing user(s) to provide the necessary data). We are keen to understand whether there is increasing interest from users in such a scenario, and invite interested parties to highlight opportunities to us, including through our Spectrum Sandbox work. We also anticipate that where more flexible equipment was available as standard, this could support further interest over time. The military is currently present in a number of bands which the global mobile vendor community is expressing an interest in for 6G, and such approaches might be considered among the range of options to meet 6G spectrum needs. This opportunity is likely to be most viable, and most readily realised, where more flexible and adaptive radio equipment is more common in civil networks.

Scenario B: Better data and open interfaces to unlock new sharing opportunities between different services, where the spectrum supply is flexed in light of data collected

3.45 Gathering and acting on local information about spectrum usage and interference levels can make for better informed spectrum management decisions. This can be especially true where the user demands for each service vary from place to place, and/or where real-world propagation may be different to assumptions made in desk-based modelling, such that geographically overlapping networks are more compatible than would be apparent without this information.

3.46 Localised sharing based on information gathered by devices happens today. Prime examples are users of unlicensed spectrum, such as Wi-Fi, or licence exempt mobile deployments including LAA (Licence Assisted Access) and 5G NR-U (New Radio Unlicensed). These scenarios rely on direct device-to-device communication, which avoids the need for a coordinating database. However, this relies upon common protocols (and typically low operating powers) to mitigate some of the challenges that a purely Cognitive Radio-type system would face (see Annex A2). Achieving this commonality is more challenging where a greater variety of communications systems are seeking to share in a single environment, and it is not a given that one set of equipment will recognise another.

3.47 There could be benefits from leveraging some of this device-level knowledge, without requiring bespoke, case-by-case standardisation of different equipment ecosystems. An aspirational ideal might be a more open and interoperable interface supported across multiple device types and services which can interact with a control point for spectrum access (e.g., an intelligent database). This would then allow access rules to be varied across these services based on evidence of real-world usage, likely collected by devices but evaluated and acted upon by an advanced database akin to a resource scheduler.[20]

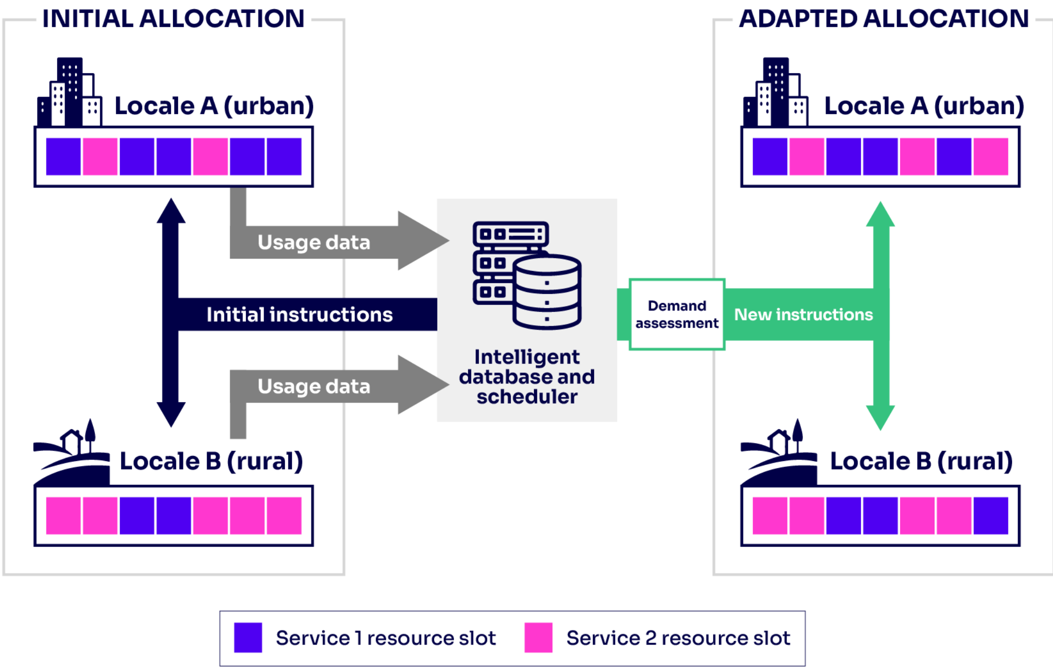
3.48 This flexible device-to-scheduler ecosystem could cater for scenarios where demand between services was uncertain, or varied by time and place. It would mean that a default starting point for the levels of time-based sharing between two services could be adapted in light of evidence from devices. This kind of approach would be data-intensive, and might

[20] We referred to the possible value of such a tool in our Spectrum Strategy, p. 54

prove burdensome for users and administrators today, but in principle could provide benefits for a number of future spectrum management decisions.

3.49 For example, a regime might begin by specifying that in urban locations, service 1 could be offered access to c70% of the available time slots, and service B offered c30% of time slots, with the level of access between the two services reversed in rural areas (based on expected differences in user demands). Under this regime, the database would require that connected devices provided feedback on spectrum use and traffic carried during an initial operational period. Based on analysis of this evidence, the most appropriate local balance of resources could be recalculated by the database. Such reviews and adaptations could be a one-off exercise, or repeated on a regular basis.[21]

Figure 3.5: Illustration of localised sharing facilitated by open interfaces between devices and database



In this scenario, we start with the majority of time slots allocated to Service 1 in Urban Areas, and for Service 2 in Rural Areas. Because data on usage is provided to the database scheduler, it can identify a better balance of spectrum resource, and after a 'demand assessment' subsequently provides an additional slot to Service 2 in urban areas, and to Service 1 in rural areas.

Source: Ofcom

3.50 It should be noted that such an ASA regime would not necessarily allow two services to fully coexist together, rather that the available time-based resource is divided in a transparent and flexible way. The benefit of this would depend on how far the two

[21] This schema is intended to be purely indicative of how such a system might work. Its deliverability will depend on demonstrating the most appropriate technical solutions to support this flexible outcome, and for these to then be deployable at scale, though research already exists on the underlying principles.

competing systems could deliver envisaged services and benefits on such a contended basis. We therefore anticipate that such an approach would ideally work best in the first instance as part of a collaborative effort between the different services and industry parties, and we stand ready to explore this in a Spectrum Sandbox environment with willing collaborators.

3.51 A simpler stepping-stone towards this kind of approach might be the integration of additional usage data into the new Automatic Frequency Coordination (AFC) mechanisms being considered to enable better user outcomes in certain bands.[22] Under current proposals, the existing user assignments which AFC-enabled Wi-Fi devices would query are expected to be characterised as 'always on' and in continuous use. Yet it is quite plausible that these users (typically fixed links) are not continuously operational, for example where they are providing additional resilience rather than acting as a primary carrier. In such a scenario, additional benefits could be enabled if the links were able to report planned operational rhythms to the database, perhaps on a daily basis.[23]

Dynamic and adaptive access will not be the solution for all scenarios

3.52 Some stakeholders have suggested that including a provision for opportunistic dynamic access as a generic condition in our licensing approach for existing users would maximise opportunities for new users, and secure efficient use. However, we believe there are many circumstances where this will not be the right thing, either for existing users, or new users. This belief reflects the potential for dynamic access regimes to bring additional cost and complexity for users, and the potential impacts on certainty of access which will not be suitable for all use cases.

- **For existing users:** Users with demanding service requirements – especially where these might include safety functions – may find dynamic sharing does not provide the certainty they need, particularly where they do not have access to sufficient other spectrum. While we recognise that hierarchies can be established to protect them, the measures this involves (whether via sensing, databases, or both) are far from cost free, and some residual risk may remain (for example, if a sharing device fails to shut down, or appears without warning). In these cases, other sharing approaches may add a greater benefit.
- **For new sharers:** Particularly where users are accessing spectrum for the first time and on which their business may depend, it is often best to provide a good amount of certainty on the level of spectrum access they can expect (and consequently the QoS their business can support). In these cases, more opportunistic access may entail extra costs and create significant challenges should that access be taken away.

[22] N.B. that here we are not commenting on the specific policy decisions relating to the upper 6 GHz band, or its future management, which we have provided an update on separately.
[23] Note that in this scenario, it would not be the case that both uses could operate 'at the same time', but rather greater benefits are leveraged from gaps in usage.

3.53 We have considered whether the opportunities we have identified as potentially flowing from more dynamic sharing might unlock new opportunities within our existing Shared Access Framework. Our current view is that for many Shared Access licensees this might not be appropriate, given this may be the only spectrum they are able to use to support their business. This judgement reflects the importance users have told us they place on certainty, and the nature of many of the services being supported in this band, such as private networks, which are predicated on very high QoS levels.

3.54 However, such users with high QoS requirements can still share with other users, (e.g., where impacts of sharing on QoS remain within a manageable threshold), and we will continue to explore other means of increasing sharing opportunities as we review our Shared Access approach. As part of this, and as highlighted above, we are prioritising an increasingly automated approach to our Shared Access licensing process from 2024, which we believe should deliver immediate benefits for users in the form of faster application turnarounds. Where this can be aligned with better data on spectrum usage and further flexibility in the licensing platform, new opportunities may come into view. We set out our further reasoning on this approach to Shared Access and more detail on our plans to begin a review of our Shared Access framework here.

4. Summary and next steps

Opportunities for more flexible, time-based sharing can be unlocked by QoS-tolerant use cases and flexible equipment

4.1 Through this document we have identified scenarios in which more dynamic (and especially more 'adaptive') approaches to spectrum allocation could enable additional spectrum usage, when matched with the right use cases and supported by flexible and open technologies.

4.2 **We are already taking steps to automate our licensing process**, updating our platforms across thousands of licenses to support simpler, quicker processes for our users. We consider this will lead to better outcomes for licensees, and by extension lead to better utilisation of spectrum in the long run. We are prioritising an early implementation of this automation for our existing Shared Access users, in recognition of the potential benefits this could bring. We are also launching a broader Call for Inputs on our future approach to authorising users in those Shared Access bands alongside this document. We will always keep our licensing tools under review and consider the opportunities for more sophisticated approaches in enabling flexible access to spectrum.

4.3 We have also identified how access to richer and more realistic data on spectrum usage will be key to enabling more spectrum sharing in the future, and can be an important foundation for establishing opportunities for more dynamic sharing. **Ofcom is undertaking work to improve the quality of data we have access to**, and committed to explore the introduction of an interference monitoring API in our Spectrum Roadmap. We will continue to progress work in this area to ensure our decision-making is grounded in the best available data. In the future, we would also be keen to facilitate greater user visibility of usage data as part of more automated licensing processes (beyond what we already provide under our open data policy) to provide greater insight on spectrum availability, and more certainty on where alternative access may be possible.

4.4 However, even where a rich dataset on spectrum usage is available, it will remain important to consider how far the needs and operating requirements of different services are suited to sharing together. Different users may have more or less fundamental differences in the times and locations of their operation, but also in their QoS needs and ability to tolerate interference and changes to their spectrum supply. Assessing how these factors will impact overall levels of service quality will form an important part of any future considerations with regards to the potential introduction of Adaptive Allocation solutions.

4.5 **We consider that the greatest potential benefits are likely to arise where this additional dynamic access is provided as a 'top up' to more certain or guaranteed spectrum access**. Typically, this opportunity may be most likely to arise for existing spectrum users with access to other bands and growing demands that may be difficult to satisfy within that existing capacity.[24] The value of this 'top up' is likely to be greatest where it can be associated with some form of confidence level or 'flexible guarantee' in the extent of that additional access.

4.6 Such models have the potential to play a role in enabling growth across a variety of sectors, including growing demand from mobile broadband and emerging 6G requirements. **We will therefore consider how such models might be used to enable hybrid solutions as we consider spectrum requirements for new and growing services in the future.**

4.7 Alongside this, we want to highlight changes within user equipment ecosystems that could enable additional and speedier implementations, and in the end deliver more efficient use of the spectrum. These opportunities include greater equipment flexibility, the standardisation of key usage KPIs and potentially the development of a blueprint for more band and service agnostic interfaces between user equipment and spectrum management databases. Such a framework might allow for simpler, less bespoke spectrum management solutions, yet still allow tailored, band-specific decision-making informed by their uses and propagation characteristics. **We encourage industry to consider how this framework could be developed, including the potential approach to securing cooperation across standards bodies, and where regulators could assist with this**.

4.8 We recognise that there may be a range of challenges and costs to such a standardisation approach, but consider that long-run benefits in the form of extra access for additional users may bring benefits for people and businesses, equipment manufacturers and regulators.

4.9 We are developing a collaborative programme of work with industry to establish **'Spectrum Sandboxes', which can provide a test ground to further explore the scope of some of these potential opportunities and the benefits afforded for spectrum users.** We will consider available outputs from any such collaborations as part of our review of our Shared Access licence, as well as their broader application to our Spectrum Management Strategy in the years to come.

[24] As noted in Section 3, this model could also be applied within a single new spectrum allocation, where part of the band is provided as a more guaranteed 'anchor' and the remainder is made available more dynamically.