Space spectrum strategy

Consultation

Consultation

Publication date: 1 March 2016

Closing Date for Responses: 10 May 2016

About this document

This document sets out our proposed Space Spectrum Strategy which covers the use of spectrum by the satellite and space science (including earth observation) sectors.

These sectors already deliver important benefits to UK citizens and consumers, such as broadcast TV, global positioning, communications to ships and aircraft, satellite imagery and information about our climate. There is potential for greater benefits in the future and we want to make sure we are focusing our efforts on the issues that we expect to unlock the biggest benefits.

We are inviting stakeholders' views on our analysis and our proposed priorities. Once confirmed, the strategy will shape the prioritisation of our work in these sectors over the coming years.

Alongside this document we are publishing visual and interactive data on the use of spectrum by the satellite and space science sectors.

Contents

Section 1

Executive Summary

1.1 Our proposed Space Spectrum Strategy builds on our overall Spectrum Management Strategy and covers the use of spectrum by the satellite and space science sectors. The latter includes meteorological satellites and earth observation.

1.2 The strategy is relevant to those aspects of our work where we have choices about how we prioritise our efforts. We are already carrying out a number of activities in the priority areas we have identified in this document. In addition to inviting stakeholders' views on whether the areas we have identified should be strategic priorities, we are also seeking views as to whether there are other regulatory interventions that we should be considering in these areas.

1.3 The strategy will not replace a fact-specific approach to particular policy issues, nor will it override our statutory duties and existing international obligations.

Citizen and consumer benefits

1.4 Satellite and space science use of spectrum enables a diverse range of important benefits to be provided to UK citizens and consumers including:

- **Satellite TV delivered to 11.2m[1] million homes,** with all TV viewers benefiting from satellite-delivered **live video of news and events** from the UK and around the world.
- **Satellite navigation and positioning services** used by millions of mobile phones and many other devices. These services also enable precise time synchronisation of the world's telecommunication networks.
- **Broadband connectivity** to people in places which are hard or impossible to reach by terrestrial networks – for example, in remote rural locations and on aircraft and ships. Satellites also enable UK citizens to communicate with parts of the world that do not yet have reliable high-capacity cabled connections.
- **Communications in emergency and disaster situations**, for emergencies at sea, in the air and at disaster sites where normal systems fail.
- **Observing the earth** and its atmosphere (using visible light or radio spectrum) from a unique vantage point, providing large amounts of information that is invaluable for a range of activities, including weather forecasting, climate monitoring, informing policy development and, increasingly, commercial applications.
- Contributing to our knowledge of space and evolution of the universe through **space research** and **radio astronomy**.

[1] Q4 2014 Pay digital satellite 9.18m; Free to view digital satellite 2.04m (CMR 2015 based on BARB survey data)

- **National security and defence,** which make use of a range of applications, including communications to vessels, aircraft (including unmanned aerial vehicles – UAVs), and land vehicles.

- Satellites also sometimes provide an alternative, or back-up, to terrestrial infrastructure. This includes helping to keep **critical infrastructure** – including energy and water networks – **operating reliably in remote locations**.

Use of spectrum and international context

1.5 The benefits above are enabled through access to spectrum both in the UK and sometimes outside the UK.

1.6 In the UK, satellites have access to 22% of the spectrum[2] between 87.5 MHz and 86 GHz. Space science applications have access to 20% of the spectrum in this range. Most of this spectrum is shared with other users, with satellite having exclusive access to 4% of spectrum and space science to 2.6% of spectrum between 87.5 MHz and 86 GHz.

1.7 In addition, spectrum use outside the UK can be important for UK citizens and consumers. For example, UK citizens benefit from live news reporting from around the world, which often uses satellite communication; from weather forecasts that are informed by satellite observations taken outside the UK; and when travelling on aircraft that provide in-flight broadband connectivity.

1.8 Further, a single satellite usually provides services to a wide geographic area, rarely just the UK, and the regulatory rules for satellites accessing spectrum at specific orbital locations are set at a global level.

1.9 Taken together, this means that our international work is particularly important in this sector.

Ofcom’s role and approach

1.10 We have a wide range of disparate functions in the satellite and space science sectors, which raise different factual and legal issues, reflecting the complex and international nature of these sectors. Our roles include:

- Authorising and protecting satellite earth stations in the UK, on the ground and sometimes on aircraft or boats. For example, we license satellite news gathering vans which are used to broadcast live video from events around the UK.

- Complying with international obligations which impact spectrum use in the space sector including, for example, EU obligations requiring protection of spectrum for the European satellite positioning system ‘Galileo’.

[2] On a weighted basis, so that lower frequencies count for more An inverse logarithmic weighting is used to adjust for the fact that at higher frequency bands there is inherently more spectrum available on a per MHz basis than at lower frequencies and that lower frequencies are generally in higher demand. So, for example, our methodology assumes that use of 100 MHz of bandwidth at 1 GHz is equivalent to use of 1 GHz of bandwidth at 10 GHz. Satellite spectrum only includes spectrum authorised by Ofcom. Space science spectrum includes all spectrum where there is a primary international allocation.

- Acting under direction from Government to represent the UK at international fora that deal with spectrum (for example, the International Telecommunications Union ('ITU'). In this role we:
    - influence the international rules that govern satellite use of spectrum, for example to encourage harmonisation of spectrum; and
    - manage satellite 'filings' for companies or other organisations registered in the UK, the British Overseas Territories, the Channel Islands and the Isle of Man. Satellite filings are the process for obtaining internationally-recognised orbital positions and spectrum frequency assignments for satellites in space.

1.11 Our proposed space spectrum strategy is relevant to the prioritisation of work for our authorisation role and informs our work on influencing international rules (in addition to wider Government objectives for the UK). It is less likely to be applicable in other areas, such as our day-to-day management of satellite filings, where we have limited discretion in relation to the exercise of our functions. Further, our approach to specific issues in individual cases will continue to be based on an assessment of the applicable facts and circumstances in each case.

1.12 Where appropriate, our spectrum work in relation to the satellite and space science sectors is guided by Ofcom's overall spectrum management strategy and our wider regulatory principles. We have translated these into a set of principles for our work in the satellite and space science sectors. Specifically, we:

- Use market mechanisms where possible and effective, but take regulatory action where necessary, recognising the particular international nature of the satellite and space science sectors.
- Look for opportunities for spectrum sharing, including managing the co-existence of different services and promoting technology improvements that minimise interference.
- Prioritise our efforts to focus on those activities where we can make the biggest improvement to UK citizen and consumer benefits.
- Lead the debate on key international spectrum issues that have particular relevance to the interests of UK citizens and consumers, and support wider international initiatives, including:
    - improvements to international rules that both support efficient allocation of global space resources and are predictable enough to enable long term investments;
    - studies (for example on new sharing opportunities) which could enhance the value of spectrum use.
- Engage with Government, as appropriate, to enable us to represent the interests of the UK in relevant international fora.
- Manage satellite filings in a thorough, fair and efficient manner consistent with international rules. To ensure we focus our efforts on filings linked to real satellite projects, we may subject UK filings to greater scrutiny than the minimum necessary under international rules.

Three proposed priorities: Broadband, earth observation and existing benefits / sharing

1.13 Where we have some discretion about how we prioritise our efforts, we have considered what we can do to generate the most value for citizens and consumers. This follows the same approach as our overall Spectrum Management Strategy. We are looking for stakeholders input on whether we identified the correct high level priorities, and whether there are any actions - in addition to those we already have planned - that we should be considering under each of those priorities.

Broadband

1.14 We propose to prioritise enabling growth in broadband communications provided via satellite to hard-to-reach locations in the UK and to aircraft and ships.

1.15 The demand for broadband data continues to grow[3], but terrestrial fixed and mobile networks do not reach all UK citizens. Satellites could, therefore, have a role in meeting this growing demand in the hardest-to-reach premises in the UK, and satellite broadband is one of the options for fulfilling the Government's ambition to make 10 Mbit/s broadband universally available.[4]

1.16 We do not believe that spectrum availability is likely to be a barrier to the growth of satellite broadband. Our analysis indicates, for example, that the current spectrum allocations could deliver enough capacity by 2020 to offer 10 Mbit/s satellite broadband to 0.7% of UK premises, and 5 Mbit/s satellite broadband (e.g. via Wi-Fi) to 80% of passengers on long-haul flights travelling in UK airspace.[5] More capacity could be available in the future, for example to support 20 Mbit/s broadband, if additional satellites were deployed.

1.17 We do not, therefore, propose to prioritise the identification of new bands for satellite broadband capacity, but we will seek to liberalise spectrum use to support new and more efficient ways of using existing allocations. For example, we will enable the use of new non-geostationary satellite networks to deliver broadband in the UK. We will also support more flexible use of spectrum by satellite terminals on aircraft and ships (building on progress we have already made at WRC-15 on 'Earth Stations In Motion'). In addition, we will consider whether the current international rules for assigning spectrum to satellites lead to inefficiencies which might justify us, working with other countries, seeking to improve the rules.

Earth Observation

1.18 We propose to prioritise enabling growth in the quality and quantity of information about the earth collected by satellites.

1.19 Citizens and consumers can benefit from better information about the world in several ways:

---

[3] Over the last 12 months, the average amount of data used on terrestrial broadband networks increased by 41% on fixed networks and 64% on mobile networks.

[4] One of the areas of focus in our Strategic Review of Digital Communications is the guarantee of universal broadband availability at a sufficient speed to meet modern consumer needs http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/digital-comms-review/DCR-statement.pdf

[5] Illustration based on 10 satellites offering ~11.7 Gbit/s each over the UK with 16QAM modulation and a 20:1 contention ratio.

- Directly, for example from improved weather forecasting and higher quality, more frequently updated satellite imagery freely available via smartphone apps;
- As a result of commercial activities (for example, insurance or farming) being provided at higher quality and/or lower cost as a result of improved information;
- Through improved public services – for example, emergency services use of weather forecasts that provide greater advance warning of extreme weather; and
- Through improved public policy as a result of policy makers having better information, particularly informing environmental policies, from measures to address climate change to planning flood defences.

1.20 The additional information collected by earth observation satellites will increase the demands on spectrum to downlink the data. Our analysis suggests that we do not need to prioritise identification of additional spectrum for earth observation data downlink as existing bands are likely to provide sufficient capacity for considerable growth. However, to get the full benefit from existing bands, we will work with public sector users to look at if, how and where earth observation applications get more certain access to the full bandwidth in these bands in the UK.

1.21 We will also support the growing numbers of small satellites by enabling access to suitable spectrum for their control. These satellites are relatively cheap to build, launch and operate, and they are helping to stimulate growth and innovation in earth observation applications. Finally, we will seek to ensure long term predictability of access to bands used for sensing, particularly passive sensing of frequency-specific physical phenomena.

Existing benefits and sharing

1.22 We propose to prioritise work that enables citizens and consumers to continue to enjoy the benefits they currently enjoy from space sector services. However, we also propose to explore in more detail spectrum sharing opportunities in the frequency bands that the space sector currently uses, and to assess the scope for new uses of spectrum in adjacent bands.

1.23 Predictability in spectrum access is also important because it helps to create an environment where operators can continue to invest in services which will provide benefits to citizens and consumers in the future. We recognise that long term predictability can be particularly important for satellite and space science use of spectrum, because of the difficulty or impossibility, for example, of modifying satellite hardware once it has been launched, and because for some space science applications, there is no choice in the frequencies that can be used – these are determined by the specific natural phenomena which the application is monitoring.

1.24 Nonetheless, there are growing and competing demands on spectrum from a range of other services, which also benefit citizens and consumers in a variety of ways. This means that we also need to consider opportunities for sharing spectrum between satellite and space science users and other spectrum users, as well as thinking about opportunities for enabling new uses in bands neighbouring those used by satellite and space science applications.

1.25 In both cases we will take care to understand and mitigate the risk of harmful interference before new services are authorised, and take effective enforcement action where necessary if problems do arise.

Other growing benefits

1.26 Other satellite applications are likely to deliver growing benefits, but, based on our current assessment, we believe there is less need for us to take regulatory action in relation to these:

- **Ultra-high definition TV content can be delivered via satellite without additional spectrum.** With anticipated technology improvements we believe that 30 UHD channels and continued growth in the number of HD channels could easily be accommodated within existing spectrum allocations.

- **Benefits from satellite navigation will continue to grow.** It will be used by more devices and applications, and we will also see the future introduction of the European Galileo satellite positioning network, but this growth will occur without major new implications for spectrum allocations in the near term.

- **Satellites could have a role in delivering the 'Internet of Things'**, but the capacity implications for most applications seem likely to be relatively small compared to growth in satellite broadband communications. We will, however, keep this under review.

- Use of satellites for **the global tracking of aircraft and for control of unmanned aircraft** will grow in importance. The key next steps are with the International Civil Aviation Organisation (ICAO), although we will continue to monitor this work.

Next steps

1.27 The consultation closes on 10 May 2016. We will update our strategy based on feedback to the consultation and publish a statement in Q3/4 2016.

Section 2

Introduction

2.1 This document consults on Ofcom's proposed strategy for the management of spectrum used by space applications. The strategy includes spectrum used by:

- Satellite communication, broadcasting and positioning applications. We refer to these throughout this document as the 'satellite' sector;
- Space science, earth observation and meteorological satellite applications. We refer to these collectively throughout this document as the 'space science' sector, although we recognise there are different ways of categorising these applications.

2.2 This section introduces the background to the strategy and its links to other work that Ofcom is undertaking.

Background

2.3 In order for us to be as effective as possible at managing use of the radio spectrum, it is important for us to have an up-to-date and thorough understanding of the trends influencing spectrum use, particularly given the increasing and competing demands for spectrum from different sectors. We published our overall Spectrum Management Strategy[6] in 2013 and have progressed more detailed reviews of a number of sectors and/or bands. For example, we developed a Mobile Data Strategy[7], and are undertaking strategic reviews of PMSE spectrum use[8] and UHF bands 1 and 2 (420-470 MHz)[9]. In addition, we are working with the public sector, where relevant, to understand its demand and potential to add to the supply of spectrum for commercial use.

2.4 The initial step in developing our Space Spectrum Strategy was to publish a Call for Input (CFI)[10] in June 2014. We received 42 responses to that CFI from a wide range of stakeholders, including commercial operators and public sector bodies. The 37 non-confidential responses are published on our website. We are grateful for the significant effort by stakeholders in contributing to that first step.

Purpose of this document

2.5 The present document outlines our findings from the CFI, set outs the principles that guide our work in the satellite and space science sectors and puts forward our proposed strategy for future work in these sectors.

---

[6] See our Consultation, Statement and Appendix of Future development in major spectrum uses at http://stakeholders.ofcom.org.uk/consultations/spectrum-management-strategy/.We also intend to make use of relevant responses to the SMS for this review, as some of those responses raised developments in the satellite and space science sectors in greater detail than was needed for the SMS.
[7] See http://stakeholders.ofcom.org.uk/consultations/mobile-data-strategy/
[8] http://stakeholders.ofcom.org.uk/consultations/new-spectrum-audio-PMSE/
[9] See http://stakeholders.ofcom.org.uk/consultations/420-470-mhz/
[10] Strategic review of satellite and space science use of spectrum - Call for input http://stakeholders.ofcom.org.uk/consultations/space-science-cfi/

2.6 Once confirmed, our strategy will inform how we prioritise our work in the satellite and space science sectors over the coming years, where we are able to do so.

2.7 Specifically, our proposed strategy is relevant to our spectrum authorisation role and will inform our work on influencing international rules. For example, the strategy will inform the priority we attach to developing new options for authorising satellite earth stations, and how we prioritise different agenda items for World Radio Conference 2019 (WRC-19).

2.8 This document does not provide a detailed summary of all individual responses and does not attempt to respond to the many individual comments made in response to the CFI. However, we have taken the responses to the CFI into account in developing our strategy. The responses have also provided us with a more refined understanding of the industry and its players, and of the satellite and space science applications using spectrum. The additional information provided, together with our on going engagement with stakeholders (through forums such as the Space Spectrum Advisory Committee and the Satellite Consultation Committee), will help to inform our future spectrum management decisions relating to these sectors.

Interactive data

2.9 We are publishing this document alongside visual and interactive data on satellite and space science use of spectrum.[11] The interactive data provide a visual summary of:

- Satellite and space science allocations from the UK Frequency Allocation Table (FAT) alongside details of products available in the UK for authorising spectrum use by satellite and space science applications.
- Information from Ofcom's licensing database for satellite earth stations.
- International Telecommunication Union (ITU) data on global satellite filings, their filing administration and status.
- Stakeholders' (non-confidential) responses to the CFI outlining their role in providing and/or using different types of satellite and space science applications.
- Stakeholders' input to the CFI on details of space science spectrum use.
- Future demand and supply, with the capability of flexing the key assumptions for the analysis.

2.10 All of the data can be searched and filtered by frequency band.

2.11 The purpose of the interactive data is to provide stakeholders with a clearer view of how spectrum is used by the satellite and space science sectors and how it can be used in the future. We are looking for stakeholder views on this interactive data and the benefits of updating the licensing and filing data on a regular basis.

[11] Space spectrum: Interactive data
http://stakeholders.acmpub.intra.ofcom.local/consultations/space-spectrum-strategy/interactive-data/

Question 1: How useful is the interactive data that we have provided on our website and why? How can the presentation and interactivity of the data be improved? How frequently would it be useful for us to update the information and why?

Other relevant work

2.12 This project is related to several other areas of Ofcom activity, including:

- **Mobile Data Strategy**. Our work has identified a number of bands with potential for future mobile data use, and we are reviewing this list in light of the outcomes of WRC-15. The bands identified so far include some with satellite use, or adjacent to bands with satellite use. This includes:
    - *3.6-3.8 GHz:* We are considering the potential for sharing between mobile and existing satellite and fixed link use, and hence if and how additional spectrum can be made available for mobile use. We intend to publish a document with our initial analysis in Q2 2016. We will also be separately publishing an update on our approach to 3.8-4.2 GHz.
    - 5-6 GHz. We intend to publish a call for inputs in the coming months to further our understanding of demand for Wi-Fi and coexistence issues in the band in Q2 2016.
    - *Bands above 24 GHz*: WRC-15 called for studies on a range of bands for future 5G mobile services, several of which are in or adjacent to bands with satellite or space science use. We are currently examining how best to contribute to these studies.
- **Further opportunities for spectrum sharing**. We will shortly be publishing our statement on spectrum sharing in response to the consultation on the framework in June 2015. Our sharing statement will address stakeholders' comments on the framework and set out actions we will take to facilitate increased sharing.
- **Review of spectrum fees for fixed links and satellite services.** We plan to consult in 2016 on changes to the fees for satellite earth stations as part of a wider fee review programme. We are sharing our analysis of demand between the fee review and our strategy work.
- **Implementation of the Radio Equipment Directive (RED).** Amongst other changes, the RED covers receiver performance and requires effective and efficient use of radio spectrum. Satellite equipment, for example Global Navigation Satellite System (GNSS) and Mobile Satellite Service (MSS) receivers, is within scope of the RED. European Harmonised Standards are now being revised for the RED and will include receiver performance parameters. This may facilitate greater spectrum sharing between different users in the future.
- **Spectrum Information**. As stated in our Spectrum Management Strategy, we are seeking to make more and better information available to stakeholders on spectrum use. The interactive visual information we are providing about space spectrum in addition to this document is an important part of this programme of activity.

Document structure

2.13 The remainder of this document is structured as follows:

- **Section 3** sets out the scope of the review and our approach to it, taking into account comments made in response to the CFI, and articulates our principles for regulating in this sector, building on our Spectrum Management Strategy.

- **Section 4** sets out the benefits to UK citizens and consumers of satellite and space science use of spectrum, and the applications provided.

- **Section 5** provides an overview of how the applications described in section 4 are currently provided, and focuses in particular on the spectrum that they use (with more information provided by our online interactive data.

- **Section 6** provides an overview of the key trends and drivers in the satellite and space science sectors.

- **Section 7** considers the implications of our findings and sets out the proposed priorities for our strategy.

Section 3

Our approach and principles

3.1 This section sets out the framework within which we have formulated the strategy proposals on which we are consulting. The framework takes into account the following:

- Ofcom's different roles in managing spectrum used by the satellite and space science sectors;
- Ofcom's legal duties in respect of spectrum management and the international context within which we carry out our spectrum functions;
- Our overarching spectrum management strategy and the principles for our work in the satellite and space science sectors;
- Our approach to the analysing the satellite and space science.

3.2 It also clarifies the scope of the strategy, taking into account stakeholder responses to the CFI.

Ofcom's role

3.3 We have a number of spectrum management roles in the space sector, reflecting its complex and international nature. Our roles include:

- Authorising and protecting satellite earth stations in the UK, on the ground and, as necessary, on aircraft and boats. For example, we license satellite news gathering vans which are used to broadcast live video from events around the UK and protect sites (by offering Recognised Spectrum Access) which are used to downlink data from meteorological satellites from interference.
- Complying with international obligations which impact spectrum use in the space sector, including, for example, EU obligations requiring protection of spectrum for the European satellite positioning system 'Galileo'.
- Acting under direction from Government to represent the UK at international fora that deal with spectrum. More specifically, Ofcom is required to provide representation on behalf of Her Majesty's Government in the UK at the ITU, European Conference of Postal and Telecommunications Administrations (CEPT), Radio Spectrum Committee (RSC) and Radio Spectrum Policy Group (RSPG), acting "as Ofcom considers appropriate"[12]. Ofcom has additionally agreed to extend its ITU representation role to the Channel Islands, the Isle of Man and the British Overseas Territories.[13] In this role we:
    - o Influence the international rules that govern satellite use of spectrum, for example to encourage harmonisation of spectrum use; and

[12] See December 2003 letter from Secretary of State to Ofcom under section 22(1) and (3) of the 2003 Act http://stakeholders.ofcom.org.uk/binaries/international/mou/MoU_2004_International_Rep.pdf

[13] In a letter dated 31 January 2005, the Secretary of State requested Ofcom to extend its ITU representation role to the Channel Islands, the Isle of Man and the British Overseas Territories. In 2005, Ofcom agreed to the Secretary of State's request http://stakeholders.ofcom.org.uk/binaries/international/mou/MoU_OTs_2007.pdf

- o Manage satellite ‘filings’ for companies or other organisations registered in the UK, the British Overseas Territories, the Channel Islands and the Isle of Man. Satellite filings are the process for obtaining internationally recognised orbital positions and spectrum frequency assignments for satellite networks.

3.4 Our proposed strategy is relevant to our spectrum authorisation role and informs our work on influencing international rules. It is less relevant to our day-to-day management of satellite filings or areas where we have limited discretion as a result of existing international obligations.

Legal duties and objectives in relation to spectrum management

3.5 As noted, we carry out a wide range of disparate functions in relation to spectrum management for the satellite and space science sectors and these are subject to differing legal requirements, under domestic, European and/or international law. We set out below our duties which are generally applicable but in individual cases, there may be other legal requirements and considerations which are of more particular relevance.

3.6 Ofcom’s principal duty, in carrying out its functions, is to further the interests of citizens in relation to communications matters and of consumers in relevant markets, where appropriate by promoting competition.

3.7 Among other duties, we are required to secure, in the carrying out of our functions, the optimal use for wireless telegraphy of the electro-magnetic spectrum, which is of particular relevance when undertaking our spectrum functions. We consider that, in general, the optimal use of spectrum is most likely to be secured for society if spectrum is used efficiently[14], that is if it is used to produce the maximum benefits for society. These benefits include both the private and broader social value associated with spectrum use.

3.8 Alongside our principal duty and our duty to secure optimal use of spectrum, we have a wide range of other duties (under the Communications Act 2003 and the Wireless Telegraphy Act 2006[15] , as well as the requirements under the European Regulatory Framework Directives) that are relevant to, and have an impact on, our spectrum decisions. These include:

- Promoting competition;
- Securing the availability throughout the UK of a wide range of electronic communications services; and,
- Securing the availability, throughout the UK, of TV and radio services of high quality and wide appeal, and duties relating to fulfilling the purposes of public service broadcasting in the UK.

[14] Nonetheless in circumstances where efficient use can only be secured at a significant cost to a particular group of citizens or consumers, we would need to consider whether this outcome would be optimal, even if it might be efficient.
[15] See in particular sections 3 and 4 of the Communications Act 2003 and section 3 of the Wireless Telegraphy Act 2006.

3.9 When taking decisions on spectrum matters we consider all relevant duties, alongside those that are directly related to our spectrum functions.

International context

3.10 Our role in representing the UK in international fora that deal with spectrum matters is particularly important given the international nature of satellite communications and regulation. As noted in our CFI, the international context is particularly important in these sectors because:

- Satellite and space science applications are typically provided on an international basis. For example, a single geostationary (GSO) satellite may provide services to nearly one third of the Earth. Space science satellites may gather measurements across the whole of the Earth in order to inform research on global climate changes.

- Spectrum use by these sectors is significantly influenced by international processes and decisions, including the processing of satellite filings by the ITU and spectrum allocation decisions at World Radio Conferences.

3.11 We also agree with stakeholders' comments in response to the CFI, which noted that, in many cases, the interests of UK citizens and consumers depend on satellite and space science use of spectrum use *outside* (as well as inside) the UK. For example:

- UK citizens benefit from live news reporting from around the world, which often depends on satellite communication.

- UK citizens on board ships and aircraft may benefit from the use of spectrum when travelling on waters or in airspace outside UK territory.

- UK citizens benefit from weather forecasts which are informed by observations (dependant on spectrum access) taken over a wide geographic area outside the UK.

- UK scientists use data that is gathered from radio astronomy sites based in other countries.

3.12 Section 4 provides more detail on the above benefits, as well as other examples of instances where UK citizens and consumers may benefit from spectrum use outside the UK.

3.13 Although spectrum use outside the UK is relevant in some ways for other sectors - for example, UK consumers benefit from economies of scale due to use of internationally harmonised mobile bands, and are able to make calls from the UK to people using mobile phones in other countries – it can be particularly important for the satellite and space science sectors.

3.14 Therefore, in addition to influencing relevant international decisions (for example, at WRCs) which can have an impact on spectrum use in the UK, we also sometimes support and promote international best practice, particularly where this may be directly relevant to UK consumers' and citizens' interests. Nonetheless, in doing so, we recognise that countries will make their own independent decisions about the best use of spectrum in their own territories.

Our principles

3.15 Ofcom follows a set of high-level regulatory principles[16] which guide everything we do. These include the principle of operating with a bias against intervention, but with a willingness to intervene firmly, promptly and effectively where required. We also strive to ensure that our interventions are evidence-based, proportionate, consistent, accountable and transparent in both deliberation and outcome.

3.16 Our overall approach to achieving our statutory goals with respect to spectrum is outlined in our Spectrum Management Strategy[17] and is relevant to all the sectors we regulate. Our overall spectrum management strategy translates into a set of principles that guide our work in the satellite and space science sectors. Specifically, we:

- Use market mechanisms where possible and effective, but take regulatory action where necessary, recognising the particular international nature of the satellite and space science sectors.
- Look for opportunities for spectrum sharing, including managing the co-existence of different services and promoting technology improvements that minimise interference.
- Prioritise our efforts to focus on those activities where we can make the biggest improvement to UK citizen and consumer benefits.
- Lead the debate on key international spectrum issues that have particular relevance to the interests of UK citizens and consumers, and support wider international initiatives, including:
    - Improvements to international rules that both support efficient allocation of global space resources and are predictable enough to enable long term investments.
    - Studies which could enhance the value of spectrum use (for example, on new sharing opportunities).
- Engage with Government as appropriate to enable us to represent the interests of the UK in relevant international fora.
- Manage satellite filings in a thorough, fair and efficient manner which is consistent with international rules. To ensure that we focus our efforts on filings linked to real satellite projects, we may subject UK filings to greater scrutiny than the minimum necessary under international rules.

3.17 As noted, we have a disparate set of functions in this area, which are carried out in a wide range of different circumstances and which may be subject to particular legal requirements and considerations. However, where appropriate, these principles may provide a useful framework for the fact and evidence-based approach that we take to consideration of particular issues.

---

[16] http://www.ofcom.org.uk/about/what-is-ofcom/statutory-duties-and-regulatory-principles/

[17] Ofcom, Spectrum management strategy - Ofcom's approach to and priorities for spectrum management over the next ten years. http://stakeholders.ofcom.org.uk/consultations/spectrum-management-strategy/

Market mechanisms

3.18 One of our key principles (noted above and in our Spectrum Management Strategy) is to 'use market mechanisms where possible and effective, but take regulatory action where necessary'. In response to our 2014 Spectrum Management Strategy consultation, some space stakeholders expressed caution about how we might apply market forces to satellite and especially space science use of spectrum, citing the international nature of satellite provision and the social value generated by some applications.

3.19 We recognise that the international nature of satellite services can, in some circumstances, limit the relevance of market mechanisms. Nevertheless, we already use market mechanisms in this sector. For example:

- We charge satellite earth stations spectrum fees in order to provide incentives for efficient use of spectrum.
- The technical conditions of auctioned licences in satellite allocated bands (e.g. 28 GHz) allow for satellite and fixed use of the spectrum. These licences are tradable and so can be acquired by satellite operators by trading with existing holders.
- Satellite filings are sometimes transferred between operators as part of commercial agreements.

3.20 We also recognise that satellite and space science applications – like many other services - can deliver wider social benefits which may not be reflected in private valuations (for example, in the amounts that companies would be willing to pay in an auction). Many of the benefits set out in section 4 are likely to reflect broader social value. In addition, in response to our CFI, a number of stakeholders said that it is difficult to estimate the benefits of scientific use of spectrum.

3.21 In light of these wider social benefits, the Government recently published a report on "Incorporating Social Value into Spectrum Allocation Decisions". This work acknowledges that placing a monetary value on broader social value is particularly difficult. However, it also explains that, where existing services can be sustained at current levels, there is no change to the social value provided by those services. In those cases, therefore, social value considerations should have no impact on spectrum management choices.

Interests of UK space industry

3.22 In responses to the CFI (and in other fora), several stakeholders asked Ofcom to explicitly take into account the interests of the UK space industry as a priority alongside UK consumer and citizen interests, citing Government objectives to grow the UK space sector.

3.23 Ofcom is an independent regulator and does not act as the representative of specific industries or companies. However, our efforts to promote optimal use of spectrum, citizen and consumer interests, innovation and competition may align with the interests of particular sectors, for example by creating regulatory conditions which are favourable for investment in new services.

3.24 In addition, our engagement with Government in relation to our international role[18] may sometimes reveal specific UK national interests which go beyond what we would promote, based on our statutory duties alone, because they reflect wider UK policy objectives. We take into account these wider UK interests in our international representation work as we consider appropriate.[19]

Our approach to the analysis

3.25 In formulating our strategy proposals for the satellite and space science sectors, we have sought to:

- Understand current use of spectrum by different applications, supported by visual and interactive data on spectrum use.

- Consider trends in different parts of the value chain - for example, the impact of evolving consumer behaviour in driving demand and the effect of new technologies and business models, and how these might affect spectrum supply and demand over the next 10 to 15 years. This timeframe reflects the long planning times and lifecycles for traditional satellite and space science investments, and the potentially long lead-time for any potential regulatory changes that require international agreement. We recognise, however, that new innovations, like nanosatellites, are developing more quickly and may lead to spectrum requirements changing over a shorter timescale.

- Review whether developments in demand and supply mean that regulatory action by Ofcom (sometimes in conjunction with regulators in other countries) is required.

3.26 In our CFI, we looked separately at 'potential mitigations' for increasing demand. We now consider potential mitigations as part of our review of technology trends (in section 6).

Scope

3.27 In response to the CFI, some stakeholders were concerned that we had omitted earth observation applications (particularly commercial applications), or that it was not clear in which sector (satellite or space science) we intended to include them.

3.28 For example, the Satellite Applications Catapult responded that it would prefer a new overarching term to cover the two parts of the 'space science' sector. It preferred 'space science' where the output is for scientific research which ultimately has significant social and environmental benefit (for example, climate change studies). It suggested a second category, 'Commercial and operational Earth Observation', to cover the application of science to real-world problems and to facilitate focus on end user need and commercial growth.

3.29 Earth observation applications – both commercial and scientific – are included within the scope of the space science sector as set out in the CFI and this consultation. Whenever we refer to 'space science' in this document we include all earth observation applications, including meteorological satellite applications. We include

[18] The Memorandum of Understanding between Ofcom and Government which covers working arrangements regarding policy lines in international meetings is set out here http://stakeholders.ofcom.org.uk/international/spectrum/mou/

[19] The Secretary of State is also able to give specific directions to Ofcom.

scientific applications where at least one element of spectrum use is connected to space (such as earth based radio astronomy), but not, for example, wind profiler radars (where there is no space element). We have also given the present document a broad title - 'Space Spectrum Strategy' - to encompass all the above space-related uses.

3.30 In the CFI we noted that the satellite sector includes military use of satellite services. Although we recognise the important benefits of military satellite use of spectrum and the need for flexibility to support military operations, we have not found it necessary to undertake a detailed analysis of demand and supply for military satellite spectrum at this time.

3.31 This is because we understand from the MOD that currently identified operational requirements could be addressed by existing spectrum allocations. In addition, based on the outcomes of WRC-15, there is no currently identified military requirement for a future WRC Agenda Item to seek new satellite spectrum allocations.

3.32 Nonetheless we are aware that increasing access to satellite capabilities will be needed to support the delivery of major military capabilities, such as the introduction into service of the Queen Elizabeth aircraft carriers. As these requirements develop we will continue to work with the MOD to take account of any significant changes in demand as appropriate.

3.33 We also noted in the CFI that the review does not cover amateur use of satellites. This remains the case, however we remain interested in views of the amateur satellite community where relevant.

Section 4

Current benefits for UK citizens and consumers

Overview

4.1 This section provides an overview of the benefits that UK citizens and consumers currently derive from satellite and space science use of spectrum, and specifies the applications that deliver those benefits. The detail of how those applications are provided using spectrum is covered in the next section.

4.2 Although we have retained reference to the applications specified in our CFI[20], in order to make the benefits for UK citizens and consumers clear we have focussed on identifying the most important high level categories of benefit. These high level benefits may be delivered by one or more of the applications from the CFI. In addition, each application may deliver more than one kind of benefit (sometimes including benefits not captured in our high level categorisation).

4.3 Our summary is informed by the considerable information on benefits provided by stakeholders in their responses to the CFI. However, given that the benefits of space applications are particularly diverse, and in order to focus our analysis, we have not attempted to provide an exhaustive list of benefits.

4.4 In addition, several stakeholders provided information about the benefits of satellite communications to the UK economy, for example through employment created by satellite operators and manufacturers based in the UK. As discussed in section 3, Ofcom's principal duty is to citizens and consumers and our strategy does not aim to identify how best to promote the UK space industry. Therefore we do not consider the broader benefits that the UK space industry provides to the UK. However, information on these benefits is available in a number of industry and Government reports.[21]

Satellite sector

4.5 The benefits that UK citizens and consumers enjoy from satellite sector use of spectrum are very diverse. The main benefits can be summarised as:

- ability to receive broadcast television content (including the direct benefits of satellite TV and the ability to watch live broadcasts of events from around the word);
- fixed and mobile broadband connectivity in locations hard to serve by terrestrial networks;

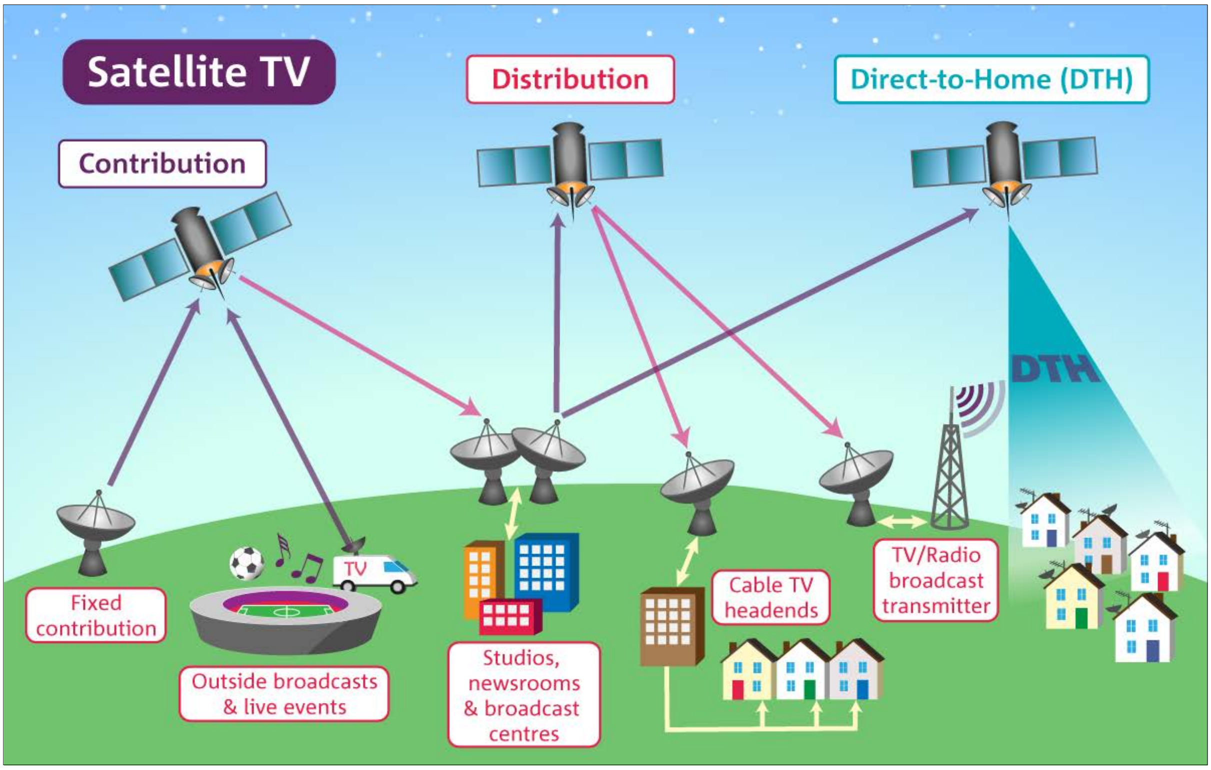
[20] The application names used in the CFI are marked in italics in this section. Stakeholders broadly supported the list of applications we provided, but suggested a number of refinements and additions which we have taken account of in the present document as appropriate.
[21] For example *The Case for Space 2015* http://www.ukspace.org/wp-content/uploads/2015/07/LE-Case-for-Space-2015-Full-Report.pdf and *The Size and Health of the UK Space Industry 2014* https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2014

- reliable critical infrastructure in remote areas;
- ability to communicate with parts of the world that lack reliable terrestrial connections;
- communications in emergency and disaster situations;
- navigation and positioning; and
- military and government use.

Broadcast TV

4.6 UK citizens and consumers benefit from the availability of satellite TV directly into their homes (**Direct-to-Home** satellite TV), as well as the use of satellites to **contribute** and **distribute** content for all TV platforms. Some typical satellite broadcast applications are illustrated in Figure 1 and outlined below.

Figure 1: Overview of typical satellite broadcast applications



Direct-to-Home (DTH) satellite TV

4.7 This involves the broadcasting of television content (both free-to-air and subscription based) from a satellite directly to consumers who receive it with a satellite dish and receiver at home.

4.8 Satellite DTH TV delivers over 500 TV channels[22] to UK households as well as digital radio. More than 11m households receive satellite DTH TV. This is 44% of the total

[22] See http://stakeholders.ofcom.org.uk/binaries/research/consumer-experience/tce-14/2_Change_Availability.pdf (page 45)

number of TV homes in the UK. Digital satellite (e.g. Freesat and Sky) accounted for 40.5% of total TV viewing hours in 2014, compared with 44.3% for digital terrestrial TV.[23] According to the BBC, 1.3 million UK households use Freesat on their primary TV sets. Some of these homes are in areas where terrestrial TV is not available and so satellite is the only free-to-view option.

Distribution of broadcast content

4.9 This involves the transmission of television, radio and interactive channels for their subsequent delivery through terrestrial broadcast, cable, and digital cinema to the end-user. For example, a satellite link can be used to distribute broadcast content from a studio to remote terrestrial broadcast towers for onward broadcast to terrestrial television viewers at home. Distribution of broadcast content can occur within or between countries, so for example can include content transmitted from overseas for distribution to UK TV platforms and vice versa.

4.10 Typical users of this application are companies offering cable head-ends, free-to-air services, channel bouquets, and distribution of television network channels to local affiliates and/or to terrestrial television broadcast towers for over-the-air broadcast.

4.11 Specific uses that stakeholders have told us about include:

- In the UK, 97% of adults tune in to BBC programming through DTT or DAB/FM transmitters which use satellite distribution links.[24]
- Satellite distribution of DTT is used in parallel with terrestrial distribution for resilience.[25]
- 1300 cinemas across Europe are equipped to receive films distributed by satellite.[26]

Contribution and Occasional Use (OU) TV

4.12 This includes the use of satellite capacity by media companies, major TV networks, news organisations, pay TV service operators, and others to move video and other content from one location to another prior to distribution to television viewers (both on satellite and non-satellite platforms). One example is satellite news-gathering earth stations that use satellite capacity to transmit live events and news stories to the studio of a TV channel.

4.13 In the UK, 280 satellite news-gathering earth stations (typically vans with roof mounted satellite dishes) are licensed for use primarily by major TV and news organisations. These organisations make a request to Ofcom when they want to transmit from a particular location for a live TV broadcast, and Ofcom receives approximately 30,000 such requests a year For example, the busiest day in 2015 was on 6 May (the day before the 2015 UK General Election) when over 200 requests for spectrum were made, involving the use of at least 70 individual satellite news gathering earth stations.

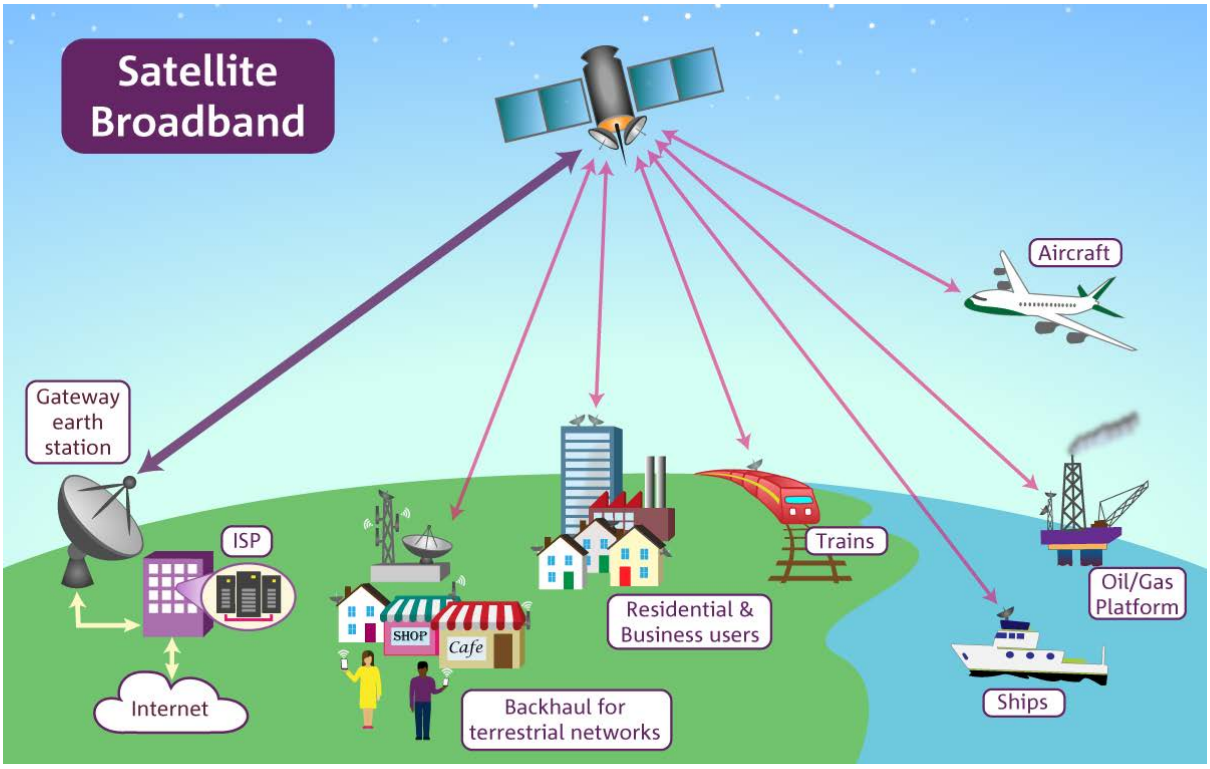
[23] The Communications Market Report, August 2015: http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/CMR_UK_2015.pdf
[24] BBC response to CFI
[25] BBC and Arqiva responses to CFI
[26] Eutelsat response to CFI

Broadband data connectivity – fixed and mobile

4.14 Residential and business consumers benefit from broadband data services provided by satellite, typically at locations where terrestrial broadband services are limited or do not exist – including remote rural locations, ships, aircraft and offshore oil and gas platforms. Some typical uses of satellite broadband are illustrated in Figure 2.

4.15 Ofcom does not currently collect statistics on the number of satellite broadband subscribers in the UK, but we will be looking into the options for doing so in the future.

Figure 2: Overview of typical satellite broadband uses



4.16 Three distinct applications provide broadband connectivity benefits:

- *Fixed Broadband internet access*: provision of fixed Internet access services to residential and business users. Satellite can also provide rapid deployment of high capacity communications to temporary business sites

- *Corporate Networks*: includes the provision to corporate users of two-way data services and telephony, for example using very small aperture terminal (VSAT) networks, usually offered subject to specific Quality of Service (QoS) contractual agreements.

- *Commercial Mobility:* mobility services to commercial and individual (i.e. non-governmental/military) users. Typical applications include broadband connectivity to aircraft, maritime communications for both vessels and offshore platforms (e.g. oil rigs), and land mobile applications (e.g. satellite phones).

Reliable critical infrastructure in remote areas

4.17 Satellites sometimes provide an alternative, or back-up, to terrestrial infrastructure. This includes helping to keep critical infrastructure – including energy and water networks – operating reliably in remote locations.

4.18 For example, satellite communications, in addition to scanning telemetry on fixed terrestrial links, are a key enabler of the SCADA (supervisory control and data acquisition) functions for critical infrastructure in remote areas. SCADA systems are of crucial importance to the smooth functioning of all major utilities.

4.19 SCADA is a form of *Machine-to-Machine (M2M) communication*, i.e. communication between devices rather than between users. At present SCADA and other forms of M2M via satellite only require limited data capacity.

4.20 Utility maintenance teams also use mobile satellite communications (see *Commercial Mobility* above) in areas where there is no other coverage or when normal systems fail.

Communication with parts of the world that lack reliable terrestrial connections

4.21 UK citizens and consumers indirectly benefit from the use of satellites in parts of the world that do not yet have reliable high capacity cabled connections such as some island nations and parts of the developing world. Without satellite connections, UK citizens could not as easily communicate or do business with those parts of the world, or benefit from live broadcasts of events from there (e.g. TV and radio reporting).

4.22 Relevant applications include broadcasting and fixed broadband data connectivity services (described above) as well as *Legacy telephony and carrier applications.* This includes point-to-point communication links purchased by commercial fixed line network companies to offer services such as private lines that can transport voice, data and video. This application may also include the leasing of capacity to be used as a backup for other links (e.g. terrestrial microwave, fibre, etc.) and/or to accommodate short periods of high demand at particular locations.

Communications in emergency and disaster situations

4.23 Satellite communications benefit UK citizens both in the UK and overseas by provision of communications in emergency and disaster situations.

- *Emergency distress alert:* satellites form the backbone of the Maritime Distress and Safety System, including detection and location of emergency beacons activated (manually or automatically) by people in distress. The most well-known example is the International Cospas-Sarsat Programme, used for identifying alerts sent by aircraft, ships, yacht owners and hikers / climbers in danger; and

- Disaster Relief: all applications that are used to provide communication services for the specific purpose of humanitarian aid and support after a disaster (e.g. earthquakes, tsunamis).

Navigation and positioning

4.24 GPS[27] and GLONASS[28], along with new systems coming on stream (notably the EU Galileo programme), provide accurate timing and positioning signals to innumerable devices (around 500 million devices in the EU[29]) in mobile devices, land vehicles, ships and aircraft worldwide.

4.25 Benefits from positioning include reduced journey times for consumers and emergency services along with efficiencies in sectors such as logistics and agriculture. Satellite positioning services are also starting to be used for spectrum management, to enable dynamic spectrum access (e.g. by TV white space devices) using geo-location.

4.26 The international telecoms infrastructure and critical timing functions now rely on these systems, rather than individual atomic clocks.

National security

4.27 The use of satellite communications supports national security. Military and government use a range of end-user and other applications, such as the deployment of Unmanned Aerial Vehicles (UAVs) and the provision of communication services to vessels, land vehicles and aircraft.

Space science sector

4.28 As noted in section 3, we use 'space science sector' as an umbrella term that covers both:

- Earth observation, including commercial and operational earth observation (which can be viewed as the commercial application of space science). Earth observation includes meteorological satellite applications.

- Space related scientific research – specifically radio astronomy and space research. The benefits from each of these areas are summarised below.

Earth Observation

4.29 Earth observation (EO) satellites observe the earth and its atmosphere, using visible light or radio spectrum from a unique vantage point. Such satellites provide large amounts of information that benefit UK citizens and consumers in a number of ways:

- **Directly in our personal lives** – for example, from use of weather forecasting and satellite imagery freely available via smartphone apps.

- As the **direct or indirect consumers of commercial activities,** ranging from insurance to farming, that can be provided at higher quality and/or at lower cost as a result of information provided by earth observation, and through the provision of new products or services.

[27] Global Positioning System
[28] GLObal NAvigation Satellite System
[29] GNSS Market Report: http://www.gsa.europa.eu/system/files/reports/GNSS-Market-Report-2015-issue4_0.pdf

- As **citizens benefiting from improved public services** - for example, the use of imagery to support local planning, or emergency services use of weather forecasts that provide advance warning of extreme weather.

- As **citizens benefiting from improved public policy** as a result of policy makers having better information, particularly informing environmental policies, from climate change to planning flood defences.

4.30 The specific downstream applications of earth observation data span the public and private sectors and vary hugely. Historically, earth observation applications have been driven and funded by government and inter-governmental organisations in order to provide the latter two (public) kinds of benefit for citizens. More recently, a growing range of commercial applications have been developed that use earth observation data.

4.31 Respondents to the CFI listed many ways in which their data can be used. We have updated the list of downstream application we provided in the CFI, and summarised these below. Nonetheless, the list is by no means exhaustive due to the diverse nature of the sector and the scope for new innovative applications to be developed.

Table 1: Overview of earth observation benefits for citizens and consumers

Weather forecasting	Data from EO satellites are used to provide weather forecasting services that directly benefit citizens in their daily lives. Forecasts also benefit citizens indirectly when they are relied upon by other services, for example aviation, transport or utilities. Extreme weather warnings alert government, emergency responders, industry, aviation and maritime, and the general public, of potential extreme weather conditions so that they can take effective mitigating action, protecting life and property.
Environmental monitoring and climate change research	Observations in this category include: • Remote sensing of the atmosphere (temperature, humidity, composition, clouds, aerosols). • Environmental monitoring (e.g. deforestation, biomass, thickness of the polar ice cap, glacier movement etc.) EO data are important for environmental protection. They are also important for improving our understanding of the climate, including projections of climate change. Better climate data can help to ensure better policy making at the national and international levels, enabling DECC and other government departments to influence global strategies for dealing with its impacts. Improved understanding of the climate can lead to better adaptation and mitigation policies and so reduced damages from climate change. In addition to the natural environment, EO can be used to monitor the urban environment, including for urban planning.

Disaster prediction and monitoring	EO data can be used in the prediction and monitoring of natural disasters (tsunamis, volcanic eruptions, earthquakes, flooding) to support advanced prediction, rescue and relief operations. Monitoring air and water pollution and the spread of hazardous substances (such as oil spills) can support public health and safety.
Defence, security and surveillance	EO can be used for national security and defence applications. Meteorological data will also be relevant to the operational effectiveness of defence activities. EO satellite data is used for enforcement activity, such as the monitoring and detection of illegal fishing, which is estimated to cost the EU 4-9bn Euros per year.
Supporting commercial activities	Many non-space industrial sectors benefit from EO data, where data can lead to operational cost savings, productivity and efficiency improvements, as well as increased safety. For example: • Agriculture - e.g. crop planning, yield estimation and crop health monitoring, which can lead to savings on irrigation and pesticides. • Supporting operation of road, rail, maritime, and aviation transport services - e.g. using satellite imagery to optimise vessel routes, for maritime surveillance and maritime equipment monitoring. • Civil infrastructure planning and monitoring - e.g. rail and tunnel subsidence, tunnel excavations and electricity distribution. • Supporting natural resource management – e.g. forestry monitoring, fisheries. • Oil, gas, and alternative energy – e.g. monitoring deployed assets and planning new installations. • Monitoring of reservoir levels and river path changes. • Supporting the insurance industry – e.g. using imaging for assessing risk and damage caused by flooding. • Provision of satellite imagery to complement the mapping data offered by commercial online services such as Google Maps.

4.32 These benefits are delivered through three main categories of space science applications:

- *Optical observation***.** Satellites with optical imaging capabilities can produce the high resolution satellite imagery which is used for a wide variety of applications.

- *Passive earth sensing:* use of receive-only sensors on satellites to monitor naturally occurring radio emissions created by the physical characteristics of Earth and its atmosphere. This includes monitoring of soil moisture and ocean salinity, sea surface temperature, surface rainfall rate, and surface wind speed

- *Active earth sensing:* Satellites transmit radio waves and then listen to the reflections that bounce back from the Earth. These can be used to precisely measure such things as fluctuations in sea levels and the thinning of forest foliage. An advanced form of active sensing is the use of multiple Synthetic Aperture Radar signals.[30]

4.33 In addition, some satellite sector applications, for example navigation and positioning, can contribute measurements that are valuable for earth observation purposes.[31] We also note the use of small satellite networks for reception of AIS (Automatic Identification System) signals for worldwide maritime security and other applications.

4.34 As discussed further in section 5, for each of these applications the satellite will separately also need to use *Earth exploration data communications,* to transmit the data it has collected down to Earth.

Radio astronomy and space research

4.35 Radio astronomy and space research contribute to our knowledge of space and the evolution of the universe. Space research also provides information about space weather, including solar activity/flares. This is vital to mitigate the risks to systems such as satellites and the national grid.

4.36 Specific applications are:

- *Radio astronomy:* use of earth stations on the ground to monitor naturally occurring radio emissions from celestial bodies and outer space, and the Doppler Effect (caused by the relative movement of the celestial bodies to the Earth and the expansion of the Universe), to aid research into astrophysics and astronomy.

- *Passive space sensing:* use of receive-only sensors to monitor naturally occurring radio emissions created by the physical characteristics of other celestial bodies and space objects. This is a radio astronomy application, but with the sensors based in space rather than on the ground.

- *Active space sensing:* use of space-borne radars for mapping other planets, comets and other space objects. Also includes the use of ground based radars to study objects in space, e.g. for detecting and ranging of satellites and space debris (satellite surveillance and tracking).

- *Space research data communications (deep space missions/near earth missions):* used for communications with space research spacecraft, for example communications with the International Space Station, deep space missions to Mars and other planets.

[30] Synthetic aperture radar (SAR) is a space borne radar used for imagining applications
[31] For example, radio occultation uses the refraction of GNSS satellite signals to provide information about the atmosphere. GNSS reflectometry involves making measurements of the reflections from the Earth of navigation signals from GNSSs.

4.37 In addition to advancing our knowledge of space, other benefits identified by stakeholders include:

- commercial ‘spin offs’ from the technology developed for research purposes. These technologies may ultimately indirectly benefit the consumers of communications services. For example, radio astronomy has contributed to technology developments in areas such as antennae, low noise amplifiers and receivers, precision timing and position measurements.

- inspirational value arising from space programmes, encouraging people to study science, technology, engineering and mathematics.

4.38 The UK hosts some important radio astronomy sites, including Jodrell Bank and Cambridge observatories and will also be a significant beneficiary from data from the Square Kilometre Array (SKA) project, which will be the world’s biggest radio telescope when completed. The SKA will be located (and hence use spectrum) outside the UK in Australia and South Africa, although its headquarters are in the UK.

4.39 The UK also benefits from (and contributes to) European Space Agency (ESA) missions, and plays an important role in various international space research missions including missions to explore other planets.

Section 5

Current provision of services

Overview

5.1 This section provides an overview of how the benefits and applications described in section 4 are currently delivered using spectrum. More detail on spectrum use is provided by our online interactive data.[32]

5.2 In the UK, satellites have access to 22% of the spectrum (on a weighted basis, so that lower frequencies count for more[33]) between 87.5 MHz and 86 GHz. Space science applications have access to 20% of the spectrum in this range. Most of this spectrum is shared with other users, with satellite having exclusive access to 4% of spectrum and space science to 2.6% between 87.5 MHz and 86 GHz (again on a weighted basis).

5.3 In addition, as discussed in section 3, one important characteristic of spectrum use by the satellite and space science sectors, is that citizens and consumers can benefit from spectrum use *outside* the UK.

Satellite sector

5.4 Every satellite communications network requires spectrum for three purposes:

- to provide services to users (the service link);
- for feeder / backhaul links between the satellite and its earth gateway station(s); and
- for telemetry, tracking and command (TT&C), to operate and control a satellite.[34]

5.5 The distinction between service links, feeder links and TT&C links is potentially significant for spectrum allocation and management since they have different implications as regards their ability to share spectrum access. Different frequencies are used for both Earth-to-space (E-s) (transmissions from an earth station to a satellite) and space-to-Earth (s-E) (transmission from a satellite to an earth station) communications where appropriate.

5.6 In addition, satellite technologies can be grouped in two main categories which have different implications for spectrum use:

[32] Space spectrum: Interactive data http://stakeholders.acmpub.intra.ofcom.local/consultations/space-spectrum-strategy/interactive-data/

[33] Satellite spectrum only includes spectrum authorised by Ofcom. Space science spectrum includes all spectrum where there is a primary international allocation. An inverse logarithmic weighting is used to adjust for the fact that at higher frequency bands there is inherently more spectrum available on a per MHz basis than at lower frequencies and that lower frequencies are generally in higher demand. So, for example, our methodology assumes that use of 100 MHz of bandwidth at 1 GHz is equivalent to use of 1 GHz of bandwidth at 10 GHz. Ofcom, Spectrum attribution metrics. http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-management-strategy/annexes/Spectrum_attribution_metrics.pdf

[34] For example, such links are used to receive monitoring data from the satellite on its health and functioning (telemetry); track the location of the satellite (tracking); send commands from the ground to the satellite to satisfy operational mission requirements or to respond to emergency conditions (command)

- Geostationary Orbit (GSO) networks include a satellite whose orbit generally lies in the plane of the Earth's equator so that it remains fixed relative to the Earth's surface. This means that the antenna on an earth station needs relatively few (if any) adjustments to its pointing direction over time.

- Non-GSO (nGSO) systems instead include satellites whose orbit means that they continuously move relative to the Earth's surface . The consequence of this is that an antenna on the earth may need to be continuously repointed to communicate with such satellites.

5.7 The differences between the two technologies above determine a different use of spectrum resources. Generally, spectrum resources can be re-used more easily amongst GSO satellite networks rather than among nGSO satellite systems. Because a user terminal communicating with an nGSO satellite needs to adjust its pointing frequently, if not continuously, the antenna is likely on occasion to point at a satellite of another constellation which may use the same frequency bands. As a consequence, if the two constellations are not managed appropriately, interference may occur.

Relevant ITU services

5.8 In the majority of cases, satellite sector applications make use of spectrum allocated to one (or more) of the following services, as defined in the ITU's Radio Regulations and summarised in simplified terms below:

- *Fixed Satellite Service (FSS)*: two-way communication links between satellites and earth stations. The earth stations are typically at a fixed point on the Earth when operating, but now also include ESIMs[35]. This service typically makes use of portions of the C, Ku and Ka bands;

- *Mobile Satellite Service (MSS)*: two-way communication links between portable user terminals and satellites The MSS is particularly well suited to providing mobile services to areas usually not reached economically by other communication means, such as oceans and polar regions. It typically makes use of portions of the L and S bands. Because of the low frequencies used, and hence low antenna gains, it is difficult to achieve co-coverage, co-frequency coordination and the use of the band is subject to a memorandum of understanding between operators that is endorsed by the ITU. Specific types of MSS include:

    - *Aeronautical Mobile Satellite Service (AMSS)*: a particular type of MSS for which the earth stations are located on board aircraft;

    - *Aeronautical Mobile Satellite (Route) Service (AMS(R)S)*: a particular type of AMSS reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes;

    - *Maritime Mobile Satellite Service (MMSS)*: a particular type of MSS for which the user terminals are located on board ships. The Global Maritime Distress and Safety System (GMDSS) also operates under this service;

[35] Earth Stations in Motion. Previously referred to as Earth Stations On Moving Platforms (ESOMPs)

- *Broadcasting Satellite Service (BSS)*: one-way transmission of high-power broadcast signals from a satellite directly to consumers, who receive the signals using relatively small and affordable satellite dishes. The service typically uses portions of the C and Ku bands;
- *Radionavigation Satellite Service (RNSS):* one-way transmission of signals from constellations of satellites towards the Earth. The coded and time-stamped signals are used to determine the position and velocity of receive-only terminals on the Earth and to synchronise a range of devices to a single time reference. These systems typically make use of portions of L band spectrum;
- *Space Operations Service (Space Operations):* communication concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space telecommand; and
- *Inter Satellite Service (ISS)*: two-way transmission of signals between two or more satellites. Typically these are used for non-geostationary constellations of satellites to relay transmissions between individual satellites.

Spectrum use

5.9 Spectrum use by satellite applications is summarised in the following table and figures:

- Table 2 summarises **how different satellite applications are provided**, the ITU radiocommunications services by which they are typically delivered, and the typical spectrum used by those applications. We have updated the information on relevant ITU services since our CFI to take account of comments received in response to the CFI.
- Figure 3 summarises information on the **role of different players in the value chain for the provision of satellite applications** based on stakeholder responses to our CFI. Although we have attempted to make the map as informative as possible, it does not attempt to provide a fully comprehensive view of the satellite sector in the UK as it is based only on the responses to our CFI. Each square on the figure shows the role of a specific organisation providing or using a particular application in a particular band (different colours representing different bands). Each organisation may play several roles in the value chain, and provide or use services in several bands. More detail (including the ability to filter by band or company) is provided in our online interactive data.
- Figure 4 complements Figure 3 by providing an overview of the different roles in the satellite value chain. The value chain we present is the same as that presented in the CFI. While we acknowledge stakeholders' comments that it would be possible to develop a more detailed value chain, we think that the value chain we are using is detailed enough to provide a high level view of the sector for the purposes of our proposals.

.

Table 2: Applications, corresponding services and typical spectrum used by the satellite sector

Application	ITU radiocommunication service(s)	Network type	Typical spectrum use
Direct-to-Home Broadcast TV	FSS, BSS	GSO	DTH TV is generally delivered to UK homes via 3 Ku band satellites located at geostationary orbital longitude 28.2 degrees East. Frequency range 10.7 – 12.5 GHz.
Distribution	FSS, BSS	GSO	Primarily Ku band but also C and Ka band.
Contribution and OU TV	FSS, BSS	GSO	Primarily Ku band but also C and Ka band. 280 news gathering earth stations are licensed for OU TV use, predominantly in Ku band and increasingly in Ka band.
Broadband internet access	FSS	GSO, nGSO	Provided using Ku band, and increasingly using High throughput Satellites at Ka band
Commercial Mobility	MSS (including ISS), FSS[36], MMSS, AMSS	GSO, nGSO	Traditionally primarily delivered by satellites using L band (around 1.5 and 1.6 GHz), and later Ku band. However, recent technology improvements (ESIMs) mean that new services are being provided using Ka band
Corporate Networks	FSS (including ISS)	GSO, nGSO	Primarily delivered by satellites using C band and Ku band
Machine-to-Machine (M2M)	MSS (including ISS), FSS	GSO, nGSO	Primarily L band and Ku band.
Emergency distress alert	MMSS (limited to the operation of the GMDSS), AMS(R)S	GSO, nGSO	Primarily L band
Navigation and positioning	RNSS	GSO, nGSO	Primarily L band

[36] The use of FSS for mobile applications is subject to various regulatory provisions (e.g. ITU-R Resolution 902 (WRC-03) or footnote No. 5.526 of the ITU RR)

Application	**ITU radiocommunication service(s)**	**Network type**	**Typical spectrum use**
Terrestrial networks backhaul, legacy telephony and carrier	FSS	GSO	Traditionally C and Ku band.
Military and government	FSS, MSS, ISS, MMSS (including the operation of the GMDSS), AMSS, AMS(R)S, RNSS	GSO, nGSO	Typically C, Ku and Ka band
Telemetry, tracking and command (TT&C)	Space Operations, FSS	GSO, nGSO	Satellite operators typically provide TT&C in the same frequency band used by the satellite’s service links.

Figure 3: Satellite applications and stakeholder roles based on stakeholder CFI responses

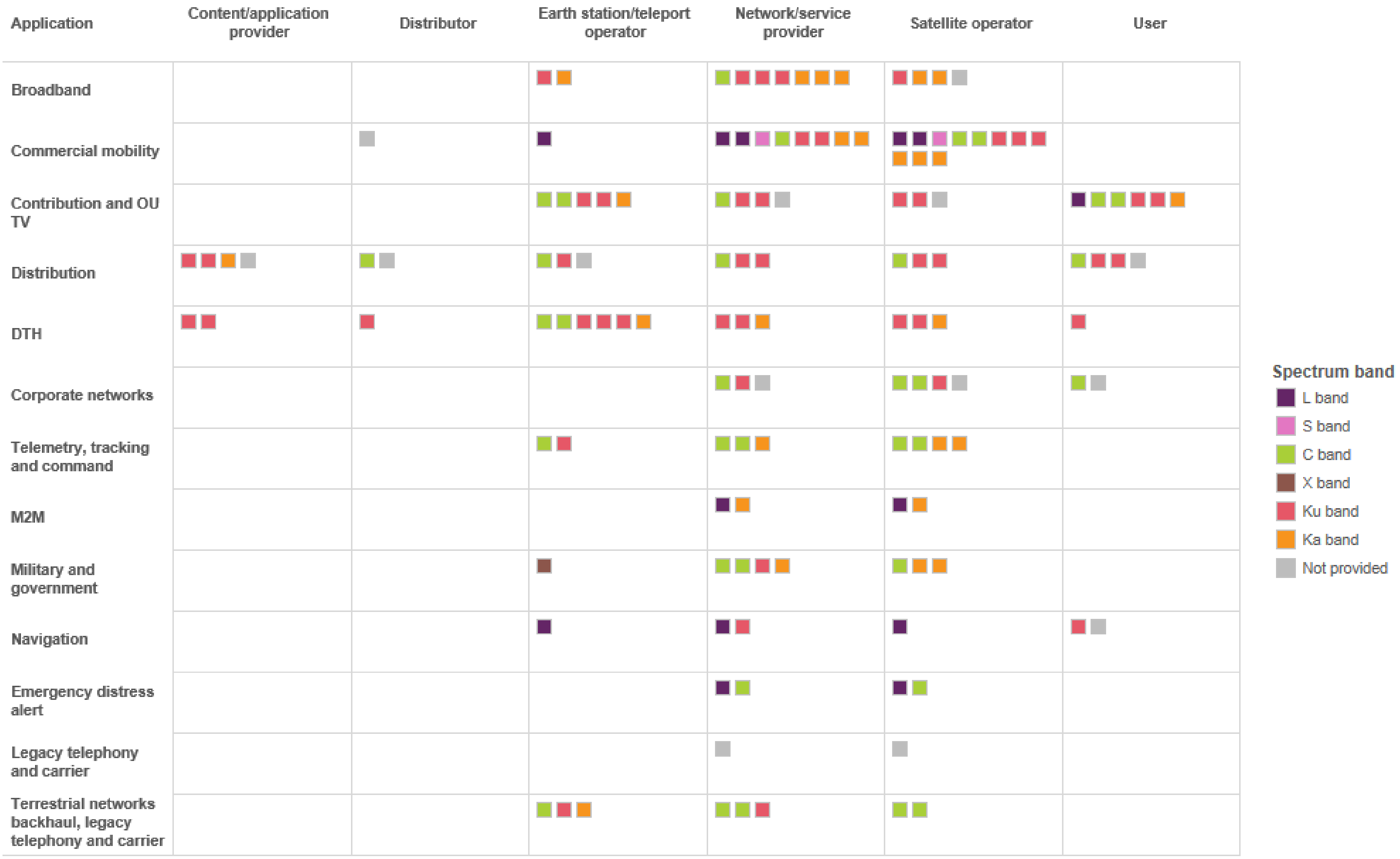
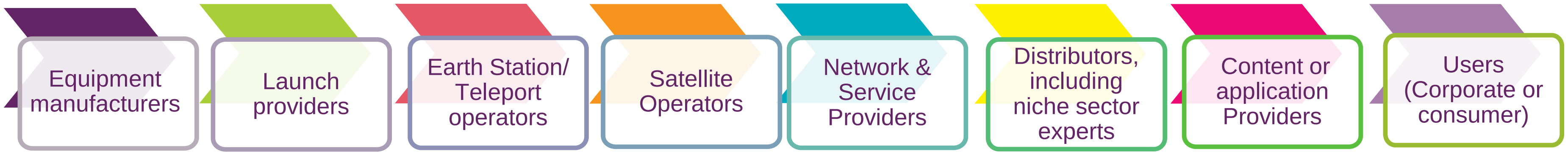


Figure 4: Satellite sector roles description



- Equipment manufacturers: manufacturers of all equipment used in the delivery of satellite services – from satellites, launchers, earth stations, to user terminals, such as DTH dishes and set top boxes;
- Launch providers: companies that offer launch facilities for both GSO and non-GSO satellites;
- Earth station/Teleport operators: companies that manage and operate earth stations and teleports for themselves or on behalf of others. A teleport is a physical site usually owned by a single company where a relatively large number of earth stations are co-located. Earth stations can be owned by a variety of organisations, provide services to a range of customers, and take a range of forms, including, for example, transportable earth stations used to provide satellite newsgathering services;
- Satellite operators: companies that procure and operate satellites to offer transponder capacity;
- Network and service providers: companies that develop networks and services using capacity leased from satellite operators for themselves or to sell to others;
- Distributors: companies that sell services and networks to end users, corporate or residential;
- Content or application providers: companies that produce content or applications that are delivered over satellite; and,
- Users: users of the applications delivered over satellite.

Space science sector

Earth Observation

5.10 Earth observation uses radio spectrum for up to three different purposes:

- **Active or passive sensing** of the earth (not relevant for optical sensing of the Earth, which relies on visible light instead of radio waves).
    - For passive applications, the frequencies suitable for particular measurements are dictated by the physical properties of the Earth's surface, atmosphere and natural radiation and there are no choices in terms of bands that they use. For example soil moisture measurements providing information relating to droughts / flooding / ocean salinity can only be performed at 1400-1427MHz.[37] The Radio Regulations contain certain provisions (for example, Footnote 5.430) that give international protection to passive services, including radio astronomy and passive space research (discussed below).
    - For active applications (where a space based radar is used), there is more choice in frequencies that are suitable for particular measurements, although the range of suitable frequencies can still be limited by the particular application. For example for measurements of the thickness of the polar ice sheet the most suitable frequency is around 400 MHz.[38]
- **Data communications** to transmit the data collected by the satellite back to Earth. For example receive-only earth stations (ROES) are used to collect data from meteorological and earth observation satellites.
- **TT&C** to operate and control the satellite (including commands on what observations to take and where).

5.11 Both GSO and nGSO systems are used; however, nGSO systems are much more prevalent than in the satellite sector because of the greater resolution and sensitivity that nGSO systems can provide for earth observation measurements due to their lower orbits. In addition, in some cases commercial satellites are used to distribute the data collected to a range of users (in contrast to the initial data downlink from the earth observation satellite). The characteristics of this application are more similar to those in the satellite sector than earth observation applications.

5.12 There are two alternative architectures for transmitting data back to Earth from nGSO satellites which have different implications for spectrum use:

- **'Data dump'**. In this architecture, satellites transmit data to earth stations when the satellite passes within the line of sight of an earth station. Data collected whilst the satellite is not able to transmit to an earth station is stored on the satellite until it is next able to. Depending on how many earth stations are in use, there can be a delay of several hours between data being collected and being transmitted to earth. Adding more earth stations can reduce this delay between

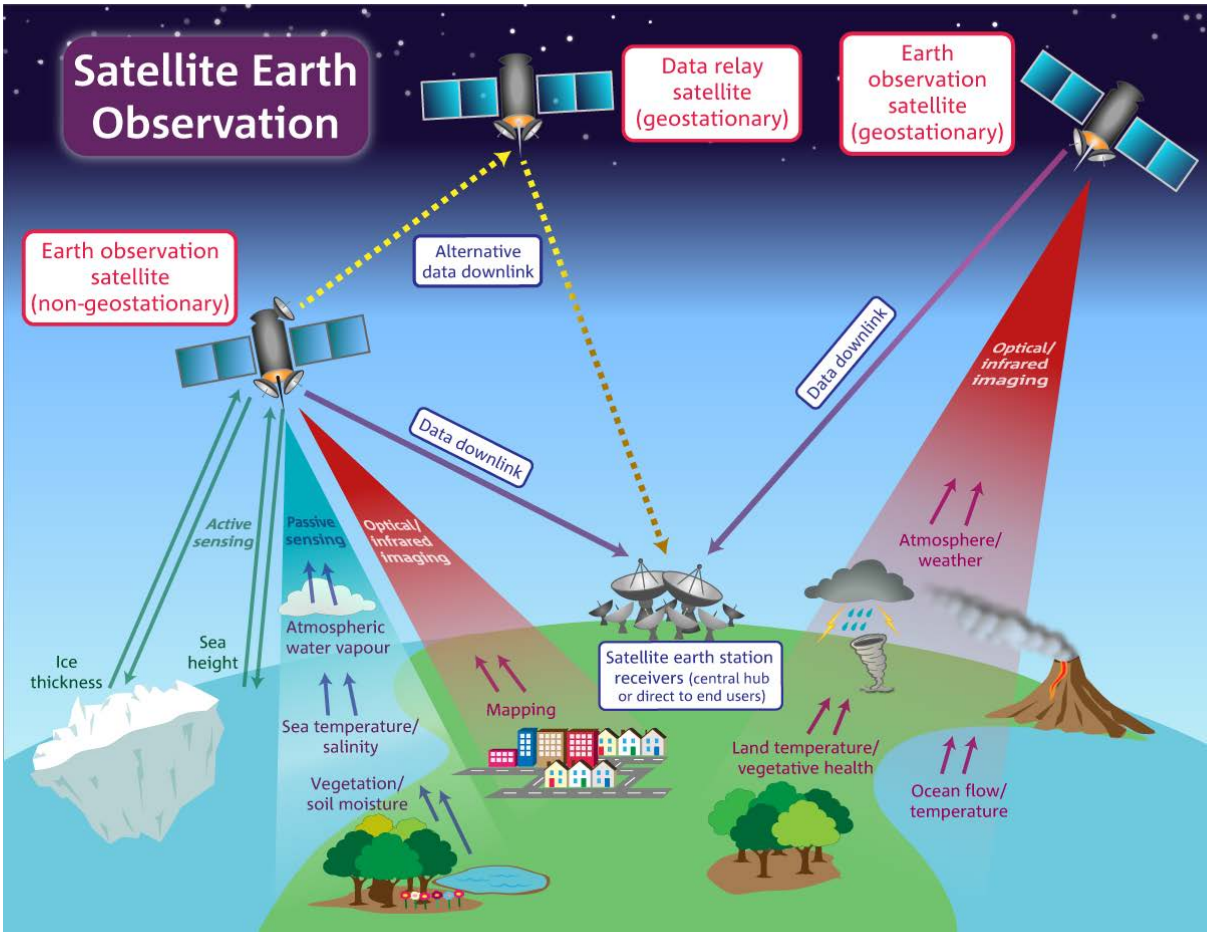
[37] Soil moisture measurements providing information relating to droughts/flooding/ocean salinity can only be performed at 1400-1427MHz due to electromagnetic radiation from hydrogen line will only occur at this frequency.
[38] The frequency around 400 MHz is the only wavelength which will penetrate through ice sheet and be reflected back when it hits rock, which in turn provides accurate information on the thickness of the ice sheet.

collection and availability. It can also increase the capacity of the system (or reduce the amount of spectrum needed) because the data dumps are more frequent meaning that less data needs to be downlinked to each earth station. However, a large number of earth stations distributed widely across the world are needed in order to minimise delays in accessing data.

- **Data relay.** An alternative is to build a relay system where data can be constantly sent from nGSO satellites to a GSO relay satellite that then transmits the data to an earth station. The deployment of a small number of geostationary satellites can enable the constant transmission of data from space to Earth and enable near real-time access to data. For example, the European Space Agency is currently building a European Data Relay System, which will relay data from the Sentinel earth observation constellation. These systems use spectrum for the link between the relay satellite and the earth station. The link between the nGSO satellite and the relay satellite may use radio spectrum or optical (laser) transmissions.

5.13 Earth observation use of spectrum is illustrated in Figure 5 below.

Figure 5: Overview of earth observation use of spectrum



Space research and Radio astronomy

5.14 Space research and radio astronomy also use spectrum for passive and active sensing as well as data communications:

- Radio astronomy is a passive sensing application and depends on access to specific frequencies where sensors are able to make measurements of naturally occurring radio emissions from outer space.

- Space based sensing can be a passive application (like radio astronomy) or an active application.

- Data communications with space research spacecraft uses spectrum for two-way communications between the Earth and the spacecraft, and communications in space, for example between different spacecraft.

5.15 In response to the CFI, stakeholders also noted that it is possible to have hybrid systems combining ground-based radio astronomy observatories together with radio telescopes on satellites.

Relevant ITU services

5.16 Space science applications make use of spectrum allocated to one (or more) of the following services, as defined in the ITU's Radio Regulations, and summarised in simplified terms below:

- *Earth Exploration Satellite Service (EESS):* the use of satellites with active or passive sensors to study the Earth and the atmosphere, including its physical characteristics (e.g. sea levels and temperature, the ozone layer), climate change, natural hazards, agriculture (e.g. droughts, crop distribution), security monitoring and disaster prediction. Includes communications links (uplinks and downlinks) between satellites and Earth stations;

- *Meteorological-satellite service (MetSat):* an earth exploration satellite service for meteorological purposes.

- *Space Research Service (SRS):* the use of spectrum to study the physical characteristics of other celestial bodies, including planets, using equipment mounted on satellites. Includes communications links (uplinks and downlinks) between space craft and Earth stations

- *Radio Astronomy Service (RAS):* the ground-based reception of naturally occurring emissions in order to research astrophysics and cosmology. Typically involves the study of celestial bodies such as pulsars, the formation of new stars, the properties of interstellar gases and plasmas, solar activity and microwave background radiation, the study of invisible mass and energy, and the expansion of the Universe; and

- *Space Operations Service (Space Operations):* communication concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space telecommand. These functions will normally be provided within the service in which the space station is operating; and

- *Inter Satellite Service (ISS):* two-way transmission of signals between two or more satellites. Typically these are used for non-geostationary constellations of satellites to relay transmissions between individual satellites.

Spectrum use

5.17 Spectrum use by space science applications is summarised in the following table and figures (similar to those presented above for the satellite sector):

- Table 3 summarises **different space science applications**, the ITU radiocommunications services by which they are typically delivered, and the typical spectrum used by those applications. We have updated the information on relevant ITU services since our CFI to take account of comments received in response to the CFI.

- Figure 6 summarises information on the **role of different players in the provision of space science applications** based on stakeholder responses to our CFI. In common with the equivalent figure for the satellite sector above, it does not attempt to provide a fully comprehensive view of the space science sector in the UK as it is based only on the responses to our CFI.

- Figure 7 complements Figure 6 by providing an overview of the different roles in the space science value chain. The value chain we use is unchanged from the CFI, apart from some clarifications to the component descriptions. However, we recognise that not all stages of the value chain will be relevant to ground-based systems (e.g. radio astronomy), which do not require “launch providers” or “satellite operators”. We also recognise that players will often contribute at multiple stages in the value chain, with overlaps and collaborations between players. Some stakeholders suggested that we add ancillary services (e.g. financial, insurance, legal) to the value chain, but we think that the value chain is sufficiently detailed to provide a high level view of the sector for the purposes of our strategic review.

5.18 Our online interactive data also provides a summary of stakeholders’ responses to the CFI on the different space science instruments used and measurements taken at specific frequencies.

Table 3: Applications and corresponding services of the space science sector

Application	**ITU radiocommunications service**	**Overview of spectrum use**
Passive applications		
Ground based radio astronomy	RAS	There are several radio astronomy sites in the UK, including Jodrell Bank and Cambridge observatories. In the UK radio astronomy uses a range of frequencies in the range 150MHz – 43.5GHz. UK scientists will also use data from the Square Kilometre Array (SKA) project, whose core sites are in Australia and South Africa.[39]
Passive earth sensing	EESS (passive)	A very wide range of frequencies are used from,1400MHz to 990GHz which are dictated by natural phenomena. The Radio Regulations contain certain provisions (for example, Footnote 5.430) that give international protection to passive services (EESS (passive), RAS, and Space Research (passive)). The Radio Regulations footnote 5.565 provides list of bands for EESS (passive) use above 275GHz.
Passive space sensing / Space-based radio astronomy	SRS (passive)	A wide range frequencies 1400MHz to 990GHz which are dictated by natural phenomena (same EESS (passive and radio astronomy) Currently the use of spectrum for Space Research (passive) is limited but expected to grow as technology developed.
Active applications		
Active earth sensing	EESS (active), Radiolocation	A number of frequencies are used depending on the type of application. These applications mostly share spectrum with radar services.

[39] The Square Kilometre Array (SKA) project is an international effort to build the world's largest radio telescope, with eventually over a square kilometre (one million square metres) of collecting area. The SKA Organisation Headquarters is in the UK.

Application	**ITU radiocommunications service**	**Overview of spectrum use**
Active space sensing	SRS (active)	As this application uses space based sensors, used in connection with mapping of other planets, it does not place constraints on other spectrum users due to the large separation distances between users.
Telecommand, Telemetry and Control	Space Operations, EESS, SRS	The key bands for TT&C for science services are 2025-2100 and 2200-2290 MHz
Space research data communications	SRS, SRS (deep space), ISS	The number of earth stations used in space research application are very small. Space research earth stations used in connection with deep space missions are highly sensitive to interference and they are typically located in remote locations around the world.
Earth exploration data communications	EESS, ISS	The key bands for EO data downlinks are X band (8025-8400MHz), and Ka band (25.5-27GHz). In the UK, the 8025-8400MHz and 26.5-27GHz are managed by the Ministry Of Defence.
Collection and distribution of information related to the weather and environment.	MetSat, EESS	The key bands are 1675-1710MHz, 8025-8400 MHz and 25.5-27GHz. Metrological data and products are also distributed via commercial satellites (FSS C and Ku bands)

Figure 6: Space science applications and value chain roles based on stakeholder CFI responses

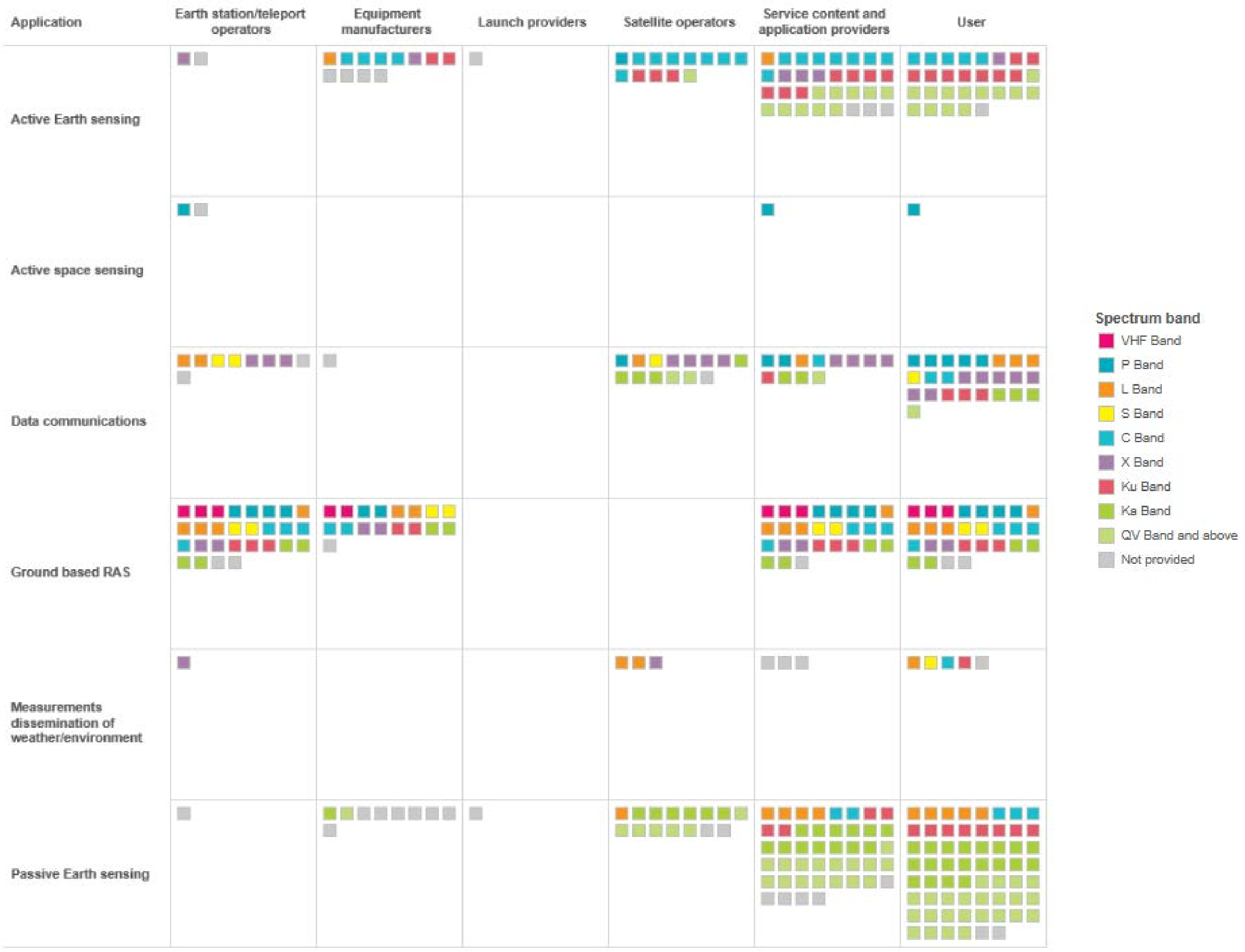
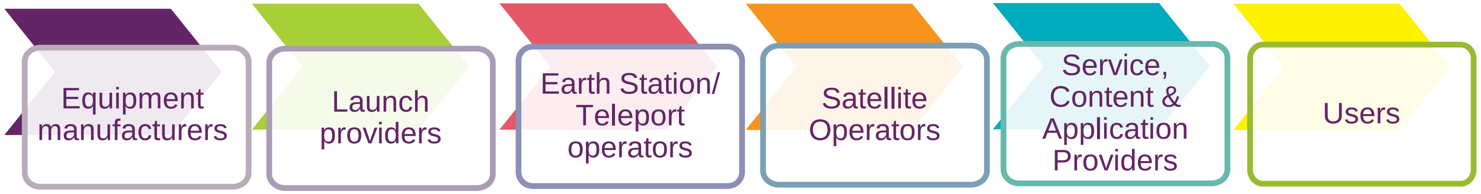


Figure 7: Space science sector value chain description



- *Equipment manufacturers:* manufacturers of all equipment (including both hardware and software) used in the delivery of space science services from satellites, launchers and earth stations. In general these are the same as for the satellite sector. Spacecraft integrators are included within this component.

- *Launch providers:* companies that offer launch facilities for both GSO and non-GSO satellites providing space science applications. Again, these are generally the same as for the satellite sector;

- *Earth station operators:* organisations that manage and operate earth stations to communicate directly with the space science satellites and other space-bound man-made objects, or receive radio emissions from celestial bodies. Some of these organisations may be the same commercial bodies that operate in the satellite sector, but they also include organisations like the Met Office, the European Space Agency (ESA) and radio astronomy observatories.

- *Satellite operators:* companies that procure and operate the space science satellites. These are usually publicly funded organisations including the ESA, EUMETSAT and NASA. They generally provide the scientific data collected by the satellites to other organisations at no cost.

- *Service, content and application providers:* entities that collect and transform data and make it available to others. Examples include the Met Office, which provides a wide range of meteorological services, and research bodies, which make available research based on space science data.

- *Users:* end users of the applications and content based on data received from space science use. There are a very wide range of end users, including the general public use of weather forecasts, public sector organisations and businesses (including the aviation sector) that make use of specialised meteorological services, and government departments that are informed by the findings of scientific research, for example on climate change.

Summary of bands used by satellite and space science sectors

5.1 Table 4 sets out at high level summary information on key bands used by satellite and space science applications where Ofcom holds data on their use in its licensing database. It also includes summary information on satellite filings provided by the ITU. This is necessarily a simplified view and full information on all bands and their use can be found in our online interactive data.

5.2 The table does not include bands used for passive and active sensing as Ofcom does not licence their use (because there are no signals transmitted from the UK).

Table 4: Overview of key bands used for satellite and space science applications

Band	Core frequency range	Typical satellite / space science applications	Summary from Ofcom licensing data (December 2016)				Satellite networks visible from UK[40] filed with ITU (Jan 2016)		
			No of PES[41] site licences	TES[42] requests in 2015	Total licensed bandwidth for PES[43] (MHz)	No. of geostationary orbital locations used by PES / TES	Notified[44]	Requested co-ordination[45]	Advanced Publication Information[46]
VHF band	149 – 149.9 MHz (E-s)		1	-	<1	-	not available	not available	not available
P band	401 – 403 MHz 432 – 438 MHz	- Meteorological data collection platforms - Active Earth sensing measurements covering Forest biomass, carbon studies, sub surface sensing, topography, glacier and ice dynamics and sea ice.	2	-	1	-	not available	not available	not available

[40] Assuming a minimum elevation of 10 degrees for the associated earth stations, geostationary satellites can provide services to the UK from orbital positions between 65 degrees West and 61 degrees East. Assuming a minimum separation of 3 degrees between satellites, this means that a maximum of 42 geostationary satellites could serve the UK at any particular frequency. Note that simply being in an orbital location that could serve the UK does not mean that the satellites will serve the UK. For example, the same orbital positions could be use by satellites which are solely serving parts of Africa.
[41] Permanent Earth Stations
[42] Transportable Earth Stations
[43] This is the total aggregated bandwidth licensed for use by PES (rounded to the nearest MHz) which is likely to be greater than what is actually used.
[44] This means that ITU has been notified that the band is currently used by a satellite network at a particular orbital location.
[45] Potential future satellites networks which have been filed with the ITU and which are in the stage of co-ordinating their potential spectrum use with other satellite networks
[46] Possible future satellite networks which have had initial information published in advance of possibly initiating co-ordination with other networks

Band	Core frequency range	Typical satellite / space science applications	Summary from Ofcom licensing data (December 2016)				Satellite networks visible from UK[40] filed with ITU (Jan 2016)		
			No of PES[41] site licences	TES[42] requests in 2015	Total licensed bandwidth for PES[43] (MHz)	No. of geostationary orbital locations used by PES / TES	Notified[44]	Requested co-ordination[45]	Advanced Publication Information[46]
L band	1 164 – 1 300 MHz 1 559 – 1 610 MHz 1 525 – 1 559 MHz (s-E) 1 626.5 – 1 660.5 MHz (E-s) 1 675 – 1 710 MHz (s-E)	- Commercial mobility - Emergency distress alert - Contribution and OU TV - Navigation - Machine-to-machine - Met Sat data downlink	1	-	60	-	31	134	1,584
S band	1 980 – 2 010 MHz (E-s) 2 025 – 2 110 MHz (E-s) 2 170 – 2 200 MHz (s-E) 2 200 – 2 290 MHz (s-E)	- Commercial mobility - Telemetry, tracking and command	5	-	55	-	2	171	875

Band	**Core frequency range**	**Typical satellite / space science applications**	**Summary from Ofcom licensing data (December 2016)**				**Satellite networks visible from UK[40] filed with ITU (Jan 2016)**		
			No of PES[41] site licences	**TES[42] requests in 2015**	**Total licensed bandwidth for PES[43] (MHz)**	**No. of geostationary orbital locations used by PES / TES**	**Notified[44]**	**Requested co-ordination [45]**	**Advanced Publication Information [46]**
C band	3 600 – 4 200 MHz (s-E) 5 250 – 5 570 MHz 5 725 – 7 025 MHz (E-s)	- Contribution and OU TV; - Terrestrial networks backhaul, legacy telephony and carrier; - Corporate networks; - Distribution; - Telemetry, tracking and command; - Military and government - Active Earth sensing	28	-	81,995	53	175	399	1,029
X band	7025-7750MHz / 7900 - 8400MHz 8025-8400MHz	- Military and government - Earth observation downlink	1	-	200	-	71	229	802

Band	Core frequency range	Typical satellite / space science applications	Summary from Ofcom licensing data (December 2016)				Satellite networks visible from UK[40] filed with ITU (Jan 2016)		
			No of PES[41] site licences	TES[42] requests in 2015	Total licensed bandwidth for PES[43] (MHz)	No. of geostationary orbital locations used by PES / TES	Notified[44]	Requested co-ordination[45]	Advanced Publication Information[46]
Ku band	10.7 – 12.75 GHz (s-E) 12.75 – 13.25 GHz (E-s) 13.75 – 14.5 GHz (E-s)	- DTH; - Contribution and OU TV; - Terrestrial networks backhaul, legacy telephony and carrier; - Corporate networks; - Distribution; - Military and government.	103	20,426	236,177	121	243	414	1,066
Ka band	17.3 – 18.4 GHz (E-s) 17.7 – 20.2 GHz (s-E) 27.5 – 30.0 GHz (E-s)	- DTH; - Broadband internet access; - Contribution and OU TV; - Corporate networks; - Distribution; - Military and government.	17	5,832	120,722	21	124[47]	1,198[47]	2,932[47]

[47] Aggregate figures for Ka band, Ka BSS and Ka Military

Band	Core frequency range	Typical satellite / space science applications	Summary from Ofcom licensing data (December 2016)				Satellite networks visible from UK[40] filed with ITU (Jan 2016)		
			No of PES[41] site licences	TES[42] requests in 2015	Total licensed bandwidth for PES[43] (MHz)	No. of geostationary orbital locations used by PES / TES	Notified[44]	Requested co-ordination[45]	Advanced Publication Information[46]
QV band and above	35.0 – 75.0 GHz	Passive earth sensing measurements for weather forecasting and climate change monitoring	-	-	-	-	41	279	979

Section 6

Trends

Overview

6.1 This section outlines the trends in the satellite and space science sectors that we have identified as potentially having the biggest impact on consumer and citizen benefits in the future, and hence they have informed the development of our strategy proposals. The analysis of trends is based on stakeholder responses to the CFI and our own research. For each sector it covers:

- Industry and technology trends which influence the capacity and capabilities of satellites and their use of spectrum, including ways of making more efficient use of spectrum.

- Application-specific trends which drive the demand for specific satellite and space science applications.

6.2 The two types of trend are, however, interrelated. Application-specific trends can spur the development and deployment of new technologies by industry. Conversely, technology developments can potentially stimulate consumer demand, by enabling improved services or reducing costs, and hence feed into the application-specific trends.

Satellite sector

Industry and technology trends

6.3 There is **increasing use of Ka band**, particularly for broadband applications. This band offers greater bandwidth than Ku band (Ku band has 750 MHz for uplink compared to 2.5 GHz in Ka band), and enables the use of narrower spot beams. However, the propagation characteristics of Ka band make it susceptible to rain fade which can lower its availability compared with other frequencies. This means that it is viewed as less suitable for broadcasting because the impact on end users of reduced availability is typically worse for broadcast services than for broadband internet services.

6.4 Improvements in antenna technology and the use of Ka band have enabled the introduction of **High Throughput Satellites (HTS)**. HTS offer a significant increase in capacity, and a consequent reduced cost per bit, compared to traditional satellites. They achieve these improvements through the use of narrow spot beams which enable a high degree of frequency re-use.[48] Although HTS currently mainly use Ka band, HTS at Ku band are on the roadmap for some operators.

6.5 Improvements in antenna technology have also enabled **higher modulation rates,** providing greater spectral efficiency compared to those supported by previous generation satellites, and hence help to further increase capacity.

[48] This is analogous to the trend towards use of smaller cell sizes in terrestrial mobile networks in order to increase capacity

6.6 **Flexible payloads** enable adjustment of the power in a beam and transponder bandwidth. The traditional design for a satellite payload has been fairly rigid in terms of defined transponder bandwidth – 27, 36, 54, 72 MHz. We are now seeing much wider transponders with the capability of linearising different power levels and feeding adjustable beams, both of which can enable more efficient use of spectrum.

6.7 **Growth in nGSO constellations,** particularly large constellations aided by mass production techniques, will provide additional capacity to supplement GSO networks as well as reduced latency as the constellations operate in lower orbits. However, at this stage it is unclear how many such networks it will be possible to deploy as the ability to coordinate a large number of co-frequency constellations has yet to be tested. Up until now simulations of these networks have not been possible. However through the ITU software is being developed to enable such simulations.

6.8 The development of **flat panel antennas**, including the ability to steer the antenna beam electronically, could reduce costs and widen the market for satellite user terminals, for example enabling them to be used in cars and smaller vessels.

6.9 Another development (currently specific to the 2 GHz band) is the potential use of **complementary ground component (CGC**) networks operating in the same band as, and coordinated with, MSS satellite networks in order to supplement their capacity.[49] These can, for example, provide additional broadband capacity to aircraft when they are travelling over land.

6.10 Other future developments that might enable further improvements in spectrum efficiency include:

- **Dynamic spectrum access technologies** (such as geo-location databases to assign frequencies to terminals) could improve the ability of satellite applications to share with terrestrial users in known locations, potentially opening up the possibility of satellite services accessing bands currently used only for terrestrial services and vice versa. However, in response to the CFI, some stakeholders noted the challenges of using this technique to share with ubiquitous or mobile devices.

- Changes to satellite network parameters to **reduce the orbital separation between GSO satellites.** In theory, such changes may be a long term option for increasing capacity if and when existing bands become congested**,** because they would increase the number of useable orbital positions that can be used co-frequency and co-polarity. However, in response to the CFI, stakeholders noted that reduced orbital separation could restrict the use of smaller antennae.

Question 2: Do you agree with the industry and technology trends we have identified for the satellite sector? Are there other trends that could have implications for spectrum use?

[49] See our consultation on the licensing of 2 GHz MSS CGC for aeronautical use http://stakeholders.ofcom.org.uk/consultations/2GHz-mobile-satellite-systems/

Application specific trends

Broadcasting (DTH TV, Contribution and distribution)

6.11 There are two potential reasons for possible increases in demand for satellite capacity for broadcasting: demand for higher resolution broadcast content and demand for additional TV channels.

6.12 Demand for **higher resolution** broadcast content, at least from some viewers, could grow as the price of large screen TV sets supporting higher resolutions (UHD 4K and possibly in the future UHD 8K) continues to fall. Nonetheless, in response to the CFI, some stakeholders – including major content providers – said that they believe that demand for HDTV programming is now approaching maturity and that the demand for UHD 4K will be limited to specific types of content, such as sport.

6.13 Although the rate of growth in demand for UHD services is unclear, we anticipate that it is likely to contribute to growth in demand for satellite capacity for direct-to-home satellite TV. In addition, demand for UHD on any platform will increase the capacity required for:

- contribution feeds, for example so that UHD content can be broadcast from live events; and
- distribution links, for example so that UHD content can be transmitted between studios.

6.14 It is less clear whether there will be demand for a **higher total number of channels** on satellite platforms. Indeed, it is conceivable that demand may fall as some viewers switch to more on-demand viewing. For example, we have seen a decline in time spent watching live broadcast TV (from 3h 45mins in 2013 to 3h 13mins in 2014) and there has been an increase in smart and connected TVs (56% of adults have a connected TV).[50]

6.15 On the other hand there is the potential for increasing demand for more channels to meet the needs of different cultural communities in the UK. This might drive demand for distribution of foreign content to the UK (for example so that it can be played out on cable networks) and for the same content to be broadcasted via satellite directly to consumers (DTH TV). Some of this content is, however, already available to consumers in the UK who have a satellite dish pointed at satellites carrying foreign content.

6.16 Two factors will help meet the demand for extra capacity:

- **End of simulcasting.** The simultaneous broadcast of channels in SD and HD on DTH (simulcasting) may cease in the future, so that capacity is freed up by stopping SD broadcasts.
- **Improvements in technology**. In particular, there is likely to be greater use of improved compression standards (e.g. HEVC) which reduce the capacity required for broadcast content, and use of improved modulation techniques (e.g. DVB-S2 or DVB-S2X) which help increase the available satellite capacity.

[50] The Communications Market Report, August 2015: http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/CMR_UK_2015.pdf

Broadband connectivity (fixed and mobile)

6.17 UK consumer demands for broadband connectivity, both at fixed locations and on the move, continue to grow. Over the last 12 months, the average amount of data used on terrestrial broadband networks increased by 41% on fixed networks and 64% on mobile networks[51]. With regards to internet traffic, Cisco predicts it will grow 3.8 fold in the UK between 2014 and 2019, with annual traffic per capita of 107GB in 2019[52]. Cisco's latest mobile forecasts, predict mobile data traffic to grow 7.2 fold in the UK between 2015 and 2020[53]. More than two thirds of UK adults own a smart phone, using it for nearly two hours every day.[54]

6.18 In addition, with growing reliance on broadband connectivity, the wide availability and high reliability of fixed and mobile broadband networks is increasingly important and remains a priority for Ofcom and for Government.[55]

6.19 Locations which are typically hard or impossible to serve by terrestrial networks – notably remote rural and off shore locations and boats and aircraft - are the ones where satellite may have an increasing role in boosting broadband availability and performance. Therefore, growing demand for broadband connectivity in general could feed through to growing demand for satellite-delivered broadband. In particular:

- Satellite is likely to have a role, alongside other technologies, in providing broadband to premises with slower fixed line (copper) broadband connections. Ofcom's Connected Nations Report 2015 indicates that 2% of UK premises are currently connected by fixed lines that are unable to support speeds of 2 Mbit/s, and 4% unable to support 5 Mbit/s.[56] The Government has recently launched a subsidised rural broadband scheme for premises that cannot get at least 2 Mbit/s and announced an ambition to make 10 Mbit/s broadband universally available.

- Satellite is currently the only way to provide broadband connectivity to aircraft over oceans and ships in offshore waters. As nearly half of UK adults travel by aircraft every year[57] and broadband connectivity on board is relatively limited, it seems likely that there will be demand for better broadband on aircraft if this can be delivered at a price consumers are willing to pay.

Positioning

6.20 The growing use of smartphones in the UK combined, with the wide range of smartphone applications which utilise location information, means that the demand for, and benefits from, satellite positioning services (complemented by positioning

[51] Connected Nations 2015 http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2015/downloads/connected_nations2015.pdf
[52] http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/vni-forecast.html
[53] http://www.cisco.com/c/dam/assets/sol/sp/vni/forecast_highlights_mobile/index.html
[54] The Communications Market Report, August 2015
[55] One of the areas of focus in our Strategic Review of Digital Communications is the guarantee of universal broadband availability at a sufficient speed to meet modern consumer needs http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/digital-comms-review/DCR-statement.pdf
[56] Connected Nations 2015
[57] Department for Transport - Public experiences of and attitudes towards air travel: 2014 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/336702/experiences-of-attitudes-towards-air-travel.pdf

information from terrestrial networks where available) are likely to continue to grow. The use of online maps is one of the top three uses of smartphones by UK consumers.[58]

6.21 In addition to growing use, there may be growing demand for accurate outdoor location information in urban areas. Today, accuracy can be reduced in some urban areas where fewer satellites are visible due to buildings partially obstructing the view of the sky. There is also demand for increased accuracy for some specialised applications, e.g. use by transport systems and emergency services, and a need for increased resilience to jamming.

Machine to Machine / Internet of Things

6.22 The Internet of Things (IoT) is set to enable large numbers of previously unconnected devices to communicate and share data with one another, boosting productivity in industries ranging from agriculture and energy to transport, healthcare and more, with the potential for significant benefits to citizens and consumers.

6.23 There are already over 40 million devices connected via the IoT in the UK alone. This is forecast to grow more than eight-fold by 2022, with hundreds of millions of devices carrying out more than a billion daily data transactions.[59] Satellite could have a role in connecting these devices in locations that are hard to serve by terrestrial networks.

6.24 Most applications which currently use M2M / IoT communication have low data rates. Although this type of communication is expected to grow substantially, we do not think that it is likely to be a significant driver of growth in satellite spectrum use. We recognise, however, that it is hard to predict future innovations in this sector – for example, car manufacturers might decide to use satellite as the primary means of communication for connected cars. We will therefore monitor the development of M2M applications as appropriate.

Question 3: Do you agree with the application specific trends we have identified for the satellite sector? Are there other trends that could have implications for spectrum use?

Space science

6.25 The key trends we have identified in the space science sector, which could have implications for spectrum use, relate to the growth of earth observation applications and their use of spectrum. When discussing industry trends in this section we include public sector use of services and applications.

Industry and technology trends

6.26 Greater miniaturisation and reduced costs of satellite technologies are enabling **significant growth in deployment of small satellites** (e.g. nano / pico satellites), for earth observation applications. These satellites are low cost, off-the-shelf products with short development and launch timelines compared to traditional satellites. This makes it possible to launch larger constellations of small nGSO

[58] The Communications Market Report, August 2015: http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/CMR_UK_2015.pdf/
[59] Promoting investment and innovation in the Internet of Things http://stakeholders.ofcom.org.uk/binaries/consultations/iot/statement/IoTStatement.pdf

satellites which are able to make **more frequent observations** of the Earth than a smaller number of large nGSO satellites.

6.27 More frequent observations mean that it is possible to provide more up-to-date data for downstream applications provided there is a suitable means for timely downlinking of data. This trend is therefore linked to the deployment of techniques for timely downlink of earth observation data (discussed in section 5). Such techniques include data relay systems and, for 'data dump' architectures, deployment of larger numbers of gateway earth stations distributed across the world.

6.28 We expect growth in numbers of small satellites to contribute to the overall **growth in number of earth observation satellites.** In addition to more small satellites, stakeholders predict a significant increase in the number of large EO satellites – from approximately 150 launches during the previous decade to approximately 360 in the next 10 years. The applications using the data from these satellites will include scientific research as well as commercial applications.

6.29 As the demand for downlink capacity grows from new earth observation missions with higher resolution sensors, satellite operators are likely to take advantage of the allocations available to them in **Ka band**, in addition to the X band allocations that they already use.

6.30 Moreover, the use of **higher level modulation** (e.g. moving from 16QAM to 32QAM), **improved on-board data compression** techniques and use of **multiple gateway earth station sites** will support greater download capacity. As noted above and in section 5, using additional gateway earth stations will both increase capacity and reduce the delay between capturing data and making it available to users.

Question 4: Do you agree with the industry and technology trends we have identified for the space science sector? Are there other trends that could have implications for spectrum use?

Application trends

6.31 There appears to be growing demand for **higher resolution imaging** to deliver more accurate observations, including data produced by synthetic aperture radars (SAR) as well as optical imaging. Demand for higher resolutions could come from commercial applications as well as public sector users. One example is the trend for increased accuracy of weather forecasts, climate monitoring and other meteorological products that (together with improvements of Numerical Weather Prediction models), are expected to drive demand for higher resolution measurements.

6.32 There also appears to be growing demand for **more frequent observations** for applications that could benefit from real time or near real time data, such as security, disaster monitoring and meteorological applications.

6.33 The above trends are also associated with **greater commercialisation of earth observation data** and wider availability of the data that is collected. As noted in section 4, earth observation applications have historically been driven and funded by governments in order to support public benefits. However, the ability to deploy small satellites with lower cost and shorter lead times than traditional satellites is now supporting the growth of commercial earth observation applications.

6.34 The range and growth of commercial applications which build on earth observation data is hard to predict but has the potential to bring benefits in a wider range of sectors, particularly as the resolution and timeliness of data is improved.

Question 5: Do you agree with the application specific trends we have identified for the space science sector? Are there other trends that could have implications for spectrum use?

Summary of areas with particular potential for growth in consumer and citizen benefits

6.35 Our analysis has identified the following applications offering the greatest potential for growth in benefits to UK citizens and consumers over the coming years. These applications and the key benefits they deliver for citizens and consumers are:

- **Broadcasting (DTH TV, contribution and distribution).** Consumers are likely to benefit from higher resolution video (more High Definition and introduction of Ultra High Definition). This applies to both consumers of direct-to-home satellite TV and consumers using other TV platforms who would also benefit from contribution and distribution of higher resolution video content via satellite.

- **Broadband access – fixed.** There is increasing potential for satellites, particularly through growing use of HTS and nGSO networks, to provide fixed broadband services in locations that are hard to serve by terrestrial networks.

- **Broadband access – mobile.** There is potential for satellites to provide greater mobile broadband connectivity in locations that cannot be served by terrestrial networks, particularly mobile broadband on aircraft and ships.

- **Navigation and positioning.** Benefits to consumers are likely to increase simply as more devices utilise existing and new satellite positioning systems. However, there may be potential for even greater benefits if the accuracy and resilience of these systems are further improved.

- **Earth Observation**. Richer, higher resolution and more frequently updated EO data are likely to benefit citizens and consumers through the downstream applications that they enable in a wide range of sectors from environmental monitoring to commercial services.

6.36 We discuss the potential regulatory implications for each of these areas in section 7.

Question 6: Do you agree with the applications we have identified as having particular potential for growth in consumer and citizen benefits?

Section 7

Implications and our proposed strategy

Overview

7.1 As noted in section 3, much of our work in the satellite and space science sectors relates to on-going activities, including:

- authorising spectrum access for satellite earth stations in the UK, and providing Recognised Spectrum Access for receive-only earth stations; and
- managing satellite filings for companies or other organisations registered in the UK, the British Overseas Territories, the Channel Islands and the Isle of Man.

7.2 We will continue this work and continue to look for ways to improve the quality and efficiency of the work we do.

7.3 In other areas we have choices about how we prioritise our work on different activities. Our strategy proposals aim to focus our efforts where they can enable the greatest benefits to UK citizens and consumers. Specifically, for each of the areas of potential future benefits for citizen and consumers identified in section 6 we have reviewed potential regulatory actions to enable those benefits to be realised over the coming years. As set out in this section, we are already carrying out a number of activities in the priority areas we have identified but invite stakeholders to comment on whether there are other regulatory interventions that we should be considering in these areas.

7.4 In summary, our proposed strategy recognises the benefits that UK citizens and consumers already gain from satellite and space science use of spectrum, and seeks to enable even greater benefits in the future. In particular, we propose to take regulatory action where necessary to:

- Enable **growth in broadband communications** provided via satellite to hard to reach locations, on land, ships and aircraft.
- Enable **growth in the quality and quantity of earth observation data** collected by satellites, which are used to provide benefits to UK citizens and consumers.
- **Enable continuation of the benefits that citizens and consumers currently enjoy** where appropriate, whilst **exploring opportunities for spectrum sharing** in the frequency bands currently used by the space sector **and new uses** in adjacent bands.

7.5 The benefits from a range of other applications could also increase in the future. As discussed later in this section (see paragraph 7.53), we believe there is less need for specific additional regulatory action by Ofcom to enable their growth.

Question 7: Do you agree with the three priorities that we have proposed for our strategy? Are there other priorities that are as important, or more important, for citizens and consumers and why?

Enabling satellite broadband growth

7.6 As discussed in section 6, the demand for broadband data services (in all locations and via all delivery technologies) continues to grow and this trend is expected to continue. However, terrestrial fixed and mobile networks do not reach all UK citizens, and so satellites could have an important role in meeting this growing demand.

7.7 Our analysis suggests three high level themes:

- we can unlock significant value by liberalising existing spectrum use to enable greater exploitation of new technologies;
- we do not need to prioritise identification of additional spectrum for satellite broadband as existing bands are likely to provide sufficient capacity for considerable growth; and
- we should carry out a high level review of the risk of inefficient use of orbital resources and the resulting impact on UK citizens and consumers, in order to inform the appropriate level of effort to focus on this issue.

Liberalising spectrum use to enable greater exploitation of new technologies

7.8 We think the key developments which could support growing benefits from satellite broadband are:

- the use of geostationary satellites to provide services to earth stations in motion (ESIMs also known as ESOMPs[60]), for example on aircraft;
- the growth of nGSO satellite constellations;
- the use of High Throughput Satellites (HTS);
- the increasing use of Ka band; and
- the use of complementary ground components.

7.9 Of these, we do not believe there is specific regulatory action needed to enable growth of use of HTS and we separately consider below (see paragraph 7.19) whether inefficiencies in allocation of orbital sources could limit benefits from use of the frequencies currently available to the satellite sector, including Ka band.

7.10 However, we believe that we should take action with regard to the other factors – namely nGSO networks, ESIMS and CGCs – to provide greater flexibility for the deployment of new technologies by liberalising spectrum use. Given the international nature of satellite applications, each of these technologies may benefit from relevant agreements at both international (ITU) and regional (CEPT) levels, as well as needing relevant authorisations in the UK.

7.11 We will therefore prioritise our work to ensure that the UK authorisation framework supports the use of these technologies. Where appropriate, we will also support international bodies undertaking relevant studies that could lead to future international agreements or recommendations. The nature of our support for such

[60] Earth Station On Moving Platforms

international work will vary, depending on the situation, from supporting the aims of the work in principle, to undertaking technical analysis ourselves and providing on going representation at international meetings.

7.12 We have already recently taken action to:

- Support an international agreement at WRC-15 on 'Earth Stations in Motion' (ESIMs)[61] that will enable extra capacity to be made available for satellite communications on aircraft and ships globally. This is already possible across Europe but a global agreement will give greater regulatory certainty that this capacity can be made available, for example, for long haul flights.

- Enable us to authorise 2 GHz MSS ground terminals which complement satellite networks being deployed at 2 GHz.[62]

7.13 We will support the use of nGSO networks and ESIMS for satellite broadband by:

- Consulting on updates to our earth station licence products to enable use with nGSO satellite networks;

- Supporting ITU work considering extending ESIM access in Ka band to include the 17.7-19.7GHz and 27.5-29.5GHz bands at WRC-19, taking into account the potential impact that this technology may have on other services sharing the same spectrum resources worldwide; and

- Supporting CEPT work on developing an appropriate regulatory framework for nGSO satellite constellations in the Ku band.

Question 8: Are there other areas where spectrum liberalisation could enable better satellite broadband services and what specific actions should we be considering?

Existing bands are likely to provide sufficient capacity for considerable growth

7.14 Our initial assessment (as set out below) is that the existing bands available, combined with continued improvements in technology, offer capacity for considerable growth in use. We do not, therefore, propose to prioritise the identification of new bands for satellite broadband capacity. In response to our CFI, stakeholders did not make strong arguments that additional spectrum was necessary.

7.15 We have considered future scenarios where satellites are used to provide broadband connectivity to a proportion of UK premises and flights travelling to and from the UK. In principle the orbital arc visible from the UK could support 42 GSO satellites.[63] Based on this assumption, we have undertaken a simple analysis of the capacity that could be provided by a number of GSO HTS satellites in Ka band. Details of our

[61] At WRC-15 Ofcom supported the agreement on ESIMs for 29.5-30 GHz as well as an agenda item for WRC-19 to consider ESIMs in 27.5-29.5 GHz
[62] http://stakeholders.ofcom.org.uk/consultations/2GHz-mobile-satellite-systems/
[63] Assuming a minimum elevation of 10 degrees for the associated earth stations, geostationary satellites can provide services to the UK from orbital positions between 65 degrees West and 61 degrees East. Assuming a minimum separation of 3 degrees between satellites, this means that a maximum of 42 geostationary satellites could serve the UK at any particular frequency.

analysis are provided in Annex 5 and we have additionally made the analysis available in interactive form.[64]

7.16 For example:

- In 2020, with 10 GSO satellites with a service area covering the UK, it might be possible to deliver:
    - o 10 Mbit/s satellite broadband (with a 20:1 contention ratio) to 0.7% of UK premises[65]; and
    - o 5 Mbit/s satellite broadband (e.g. via Wi-Fi) to 80% of passengers on long-haul flights travelling in UK airspace at any given time (with a 20:1 contention ratio).
- In 2025, if the market continues to grow, assuming 22 GSO satellites with a service area covering the UK and further improvements in technology, it might be possible for:
    - o 20 Mbit/s satellite broadband (with a 20:1 contention ratio) to be provided to 1% of UK premises; and
    - o 90% of passengers on all long-haul flights travelling over UK airspace at any given time to use broadband (e.g. via Wi-Fi) on board the flight at 10 Mbit/s (with a 20:1 contention ratio).

7.17 A wide range of other scenarios are possible and our online interactive data allows examination of the implications of different assumptions. The services provided in practice, and the level of take-up, will depend on commercial decisions and the cost of providing services via satellite, including their cost relative to terrestrial options where these are practical.

7.18 The above estimates do not include capacity from nGSO networks offering broadband services in the UK and therefore in that respect are an underestimate of the capacity that might be available. In addition, GSO satellites operating in other bands (e.g. Ku band) can provide broadband services, but those bands will also be used for a range of other applications such as distribution of broadcast content.

Question 9: Do you agree that existing bands are likely to provide sufficient capacity for considerable growth in satellite broadband and that we do not need to prioritise the identification of new bands? Do you have any comments on the analysis we have undertaken of supply and demand?

[64] Space spectrum: Interactive data http://stakeholders.acmpub.intra.ofcom.local/consultations/space-spectrum-strategy/interactive-data/

[65] Assuming there are 29 million UK premises, which is a figure derived from data published with the Connected Nations Report 2015: http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2015/downloads/connected_nations2015.pdf

Assessing the risk of inefficient use of global spectrum and orbital resources

7.19 Realising satellite broadband benefits also depends on the efficient use of global spectrum and orbital resources. However, there is a growing proliferation of filings to the ITU for proposed satellites, some or many of which may not be for genuine satellite projects, i.e. they could be ‘paper satellites’. There is a risk this leads to inefficient use of spectrum and potentially has a negative impact on the provision of satellite broadband services to UK citizens and consumers (for example, if demand for additional satellite broadband capacity to the UK could not be met as a result).

7.20 The potential problem is illustrated by data from the ITU that indicates that in Ka band there are:

- 514 satellite filings, in orbital locations visible from the UK, which are in the stage of co-ordinating their potential spectrum use with other satellite networks – an average of 12 for each of 42 potential orbital locations; and

- 1057 possible future satellite networks which have had initial information published in advance of possibly initiating co-ordination with other networks – an average of 25 for each of 42 potential orbital locations;

7.21 The proliferation of filings may create uncertainty for investment in use of spectrum, delays to new services and potentially barriers to entry for new competitors. This is not a risk for the UK alone and it is certainly not a problem that the UK can tackle in isolation given that international rules govern satellite filings.

7.22 Therefore we will undertake research to assess the level of risk and magnitude of its impact with a view to ensuring that, where necessary, we apply the appropriate level of effort to this issue and influence the international debate at a strategic level. Any action to effectively address this risk will need coordinated action by several countries that are able to influence the relevant international rules effectively.

Question 10: To what extent does the proliferation of filings for ‘paper satellites’ create costs or barriers that hinder the provision of satellite services to UK citizens and consumers?

Question 11: Are there other actions we should be considering that could enable greater benefits from satellite broadband?

Enabling Earth observation growth

7.23 Although satellite-based observations of the earth and its atmosphere are not new, there is an opportunity for UK citizens and consumers to benefit further from the insights that more and higher quality earth observation can bring.

7.24 Our analysis suggests four high level themes:

- We do not need to prioritise identification of additional spectrum for earth observation data downlink as existing bands are likely to provide sufficient capacity for considerable growth.

- However, to get the full benefit from existing bands, and so support growth in data downlink requirements, we will work with public sector users to look at if, how and where earth observation applications can access the full bandwidth.

- We can support the growing numbers of small satellites by enabling access to suitable spectrum for TT&C.
- We should seek to ensure long term predictability of access to bands used for sensing, particularly passive sensing of frequency-specific physical phenomena.

Existing bands are likely to provide sufficient capacity for considerable growth

7.25 Our initial assessment is that growing demand for data downlink capacity, and for timely access to frequently updated data, can be met through a combination of deployment of additional gateway earth stations for receiving this data, deployment of data relay satellites and use of spectrum allocated to the EESS in Ka band (25.5-27 GHz; this is distinct from Ka band spectrum allocated to the FSS which is suitable for broadband applications).

7.26 At present many EO missions use X band (8025-8400 MHz) for downlinking their data, but Ka band offers four times the bandwidth of X band. Data could also be downlinked from a geostationary data relay satellite using FSS allocations in Ka band, offering further capacity (although this would compete with a wider range of other applications, such as broadband discussed above).

7.27 In order to test whether the existing allocations suitable for earth observation data downlink in X band and Ka band are likely to be sufficient we have considered some simplified future scenarios. Specifically, we have assessed the downlink data rate that might be required by a high resolution optical earth observation satellite in the future, and compared this against the potential data rate that could be achieved using existing EESS allocations in X band and Ka band.

7.28 In summary:

- In 2020, a satellite capturing panchromatic[66] images with a resolution of 0.25 metres (i.e. each pixel is 0.25 metres across) and 1.85 metre multispectral (multicolour) images would need a data downlink of **4.6 Gbit/s**. The majority of this data requirement is generated from the high resolution panchromatic image.
- In 2025, the images of the same resolution would need a data downlink of **4.2 Gbit/s**. The lower data requirement is due to assumed improvements in data compression on board the satellite, which are to some extent offset by increased data requirements from capturing high resolution data over a larger geographic area.
- We estimate that this data requirement could be accommodated within existing allocations in Ka band and X band, which could provide a total capacity of **4.8 Gbit/s** in 2020 and **6 Gbit/s** from 2025 onwards.

7.29 We have focused on the data requirements of a single satellite on the assumption that different satellites will continue to co-ordinate their spectrum use so that they can effectively share the X and Ka band. At present we do not foresee the same sorts of concerns over proliferation of satellite filings as have arisen in the other (FSS allocated) parts of Ka band used for satellite broadband applications (discussed above). Conceivably this might change in the future, with greater commercialisation

[66] A monochrome image capturing data from all visible light parts of the electromagnetic spectrum

of the earth observation sector, and therefore we will continue to monitor the situation.

7.30 Full details of the assumptions we used in this analysis are available in Annex 5.

Question 12: Do you agree that existing bands are likely to provide sufficient capacity for considerable growth in earth observation data downlink and that we do not need to prioritise the identification of new bands? Do you have any comments on the analysis we have undertaken of supply and demand scenarios?

Deployment of gateway earth stations for data downlink

7.31 Our findings, above - that existing bands provide sufficient capacity for considerable growth **–** assumes that the whole of the EESS allocated parts of X and Ka band are available for downlink and that data can be transmitted continuously. One of the options for achieving this is through a network of gateway earth stations.

7.32 Therefore, we think it will be beneficial for stakeholders to deploy earth stations in the UK that can access the full EESS allocations and for their use of those earth stations for downlink data to be protected from harmful interference.

7.33 We already offer Recognised Spectrum Access (RSA) in bands that we manage and which are used for earth observation downlink (specifically spectrum allocated to EESS in 25.5 – 26.5 GHz). RSA enables receive only earth stations in those bands to be protected from harmful interference from other spectrum users. Hence stakeholders downlinking earth observation data have greater certainty of access to spectrum than ‘opportunistic’ use (where data can be received but with no guarantees about future access).

7.34 In addition, some of the spectrum allocated for EESS is managed by the public sector (specifically the MOD), in particular 8025 – 8400 MHz (in X band) and 26.5 – 27 GHz (in Ka band). Therefore access to that spectrum – on a geographically shared basis **–** is likely to help support growing data downlink requirements. We will continue to work with the MOD to consider if, how and where access can best be provided.

Question 13: What other specific actions should we be considering to facilitate earth observation data downlink?

Supporting the growing numbers of small satellites by facilitating access to suitable spectrum for TT&C

7.35 As noted in section 6, one of the important trends in the sector is the growth in use of small satellites and the scope for innovation they open up due to lower costs and shorter development lead times. Large constellations of small satellites can provide more frequently updated earth observation data.

7.36 However, one potential issue for the deployment of small satellites is spectrum availability for TT&C. In particular there is scope for harmonised spectrum at relatively low frequencies (below 1 GHz) to support the deployment of small satellites and result in lower costs. These satellites typically use omni-beam antennae because of the availability of lower cost equipment, and need lower frequency spectrum because of the low gain of these antennae. Although spectrum below 1 GHz is very intensively used, TT&C requires only a very narrow bandwidth (perhaps no more than a few hundred kHz).

7.37 We have already engaged with public sector spectrum users to facilitate sharing of public sector spectrum with earth observation TT&C. We have also successfully supported an agenda item for WRC-19 to assess the suitability of existing allocations and, if necessary, consider the potential global identification of bands suitable for control of small satellites.

7.38 Going forward we will support the work of WRC-19 to study the spectrum needs for small satellites with short duration missions and continue to work with public sector users on potential sharing opportunities.

Question 14: To what extent will access to suitable spectrum for TT&C enable greater use of small satellites and why? Do you agree with the specific actions we have identified and what else should we be considering?

Long term predictability of access to bands used for sensing

7.39 The key issue for earth observation applications that rely on spectrum for active or passive sensing is the predictability of spectrum access over long periods of time. This is especially important for passive sensing (for example radio astronomy or monitoring of soil moisture) which depends on access to bands which are determined by specific natural phenomena.

7.40 There are two aspects to our approach to this issue, reflecting both the risk of new services causing interference to sensing bands, and the sensitivity of satellites in those bands to interference:

- We already have a range of tools available to us to deal with cases of interference into sensing bands and we take appropriate care before deciding to introduce new services, either adjacent to (or for active bands, potentially co-channel with) bands using for sensing. For example, studying co-existence with adjacent passive bands will be particularly important when considering potential 5G bands under WRC-19 Agenda Item 1.13.

- We plan to support international work on filtering to provide guidance, and improvements in filtering for satellites making observations in passive bands. The aim is to reduce the risk of future services in adjacent bands causing interference into those satellites (or imposing unnecessary costs through constraints on the operation of those other services).

Question 15: What other actions should we be considering to support long term predictability of access to sensing bands?

Question 16: Are there other actions we should be considering that could enable greater benefits from earth observation?

Enabling existing benefits whilst exploring sharing and new uses

7.41 We propose to prioritise enabling the benefits that citizens and consumers currently enjoy to continue, where appropriate, whilst recognising competing demands for spectrum.

7.42 As well as supporting existing benefits, predictability of spectrum access is important to provide an environment where operators can continue to invest in services which will provide benefits to citizens and consumers in the future. We recognise this can be particularly important for satellite and space science use of spectrum, because:

- the lifetimes for satellite and space science investments are often long (traditionally 10 to 20 years), although this is changing for small satellites which can have a much shorter lifetime (perhaps as little as 6 months to 2 years);
- it is difficult or impossible to modify space-based hardware once launched (although some operational changes can be made to software), again noting that small satellites may be replaced relatively frequently;
- some applications are especially sensitive to interference from other spectrum users over a wide geographic area (usually international); and.
- for passive space science applications, there is no choice in the frequencies that can be used as these are determined by specific natural phenomena.

7.43 Nonetheless, there are growing and competing demands on spectrum from a range of other services which also benefit citizens and consumers in a variety of ways. This means that we also need to consider opportunities for sharing spectrum – both terrestrial services accessing bands currently used only for satellite services and vice versa **–** as well as opportunities for enabling new spectrum use alongside satellite and space science use.

7.44 To enable the continuation of existing benefits whilst allowing potential new uses of spectrum, we

- take care when introducing new services to understand, and where appropriate, mitigate the risk of harmful interference; and
- can take specific action, for example enforcement, to deal with problems should they arise in practice.

7.45 We do not propose to make significant changes to the way we approach the measures we take in this regard, but welcome stakeholders' feedback on any improvements we should consider.

Taking care when introducing new services

7.46 Spectrum sharing is an important element of our overall spectrum strategy and we published a consultation on a framework for spectrum sharing[67] which sets out our proposed approach in more detail. We will shortly be publishing a statement on the sharing framework.

7.47 Consistent with our consultation on the sharing framework, we will always need to consider the relative merits of any spectrum sharing opportunity. Therefore, where there is potential benefit from the introduction of new applications sharing with, or operating adjacent to, satellite and space science use (or indeed other uses) of spectrum, we need to consider such changes carefully, including the benefits delivered by incumbent services and the incremental impact of sharing on incumbents, e.g. on their incentives to invest.

[67] Ofcom, A framework for spectrum sharing. http://stakeholders.ofcom.org.uk/consultations/spectrum-sharing-framework/

7.48 We undertake co-existence studies to establish the feasibility and conditions for sharing and will continue to do so. We will also maintain a focus on how sharing can be implemented effectively in practice as well as in theory, in response to stakeholders' demands for more opportunities to access shared spectrum. For example, we are applying this approach in our work on potential sharing between terrestrial services and satellite services in 3.6-3.8 GHz, and with space science services in 5-6 GHz. We will also do so when participating in studies on bands above 24 GHz for potential use by terrestrial mobile services.

7.49 In addition, we will continue to promote good practice internationally, for example through the CEPT and ITU. This is particularly important where those bodies are considering enabling new services, including, for example, seeking changes to Radio Regulations, where there is a risk to the benefits currently enjoyed by UK citizens and consumers.

Protecting from interference

7.50 Complaints of interference affecting satellites or satellite earth stations in the UK are rare. However, problems can arise from malfunctioning equipment or unlicensed transmissions. Although we do not offer a guarantee of interference free spectrum, in cases where the source of unlicensed use or source of interference is within the UK we may:

- Provide advice and assistance;
- Investigate and resolve specific sources of interference/unlicensed use;
- Where appropriate use enforcement powers to abate interference/unlicensed use;
- Remove non-compliant radio and electrical apparatus from the market;
- Cooperate with other regulators (within the EEA) to share intelligences on non-compliant radio apparatus or electrical products;
- Conduct pro-active targeted market surveillance activities.

7.51 If stakeholders experience problems due to terrestrial transmissions authorised outside the UK, then we would normally expect operators to address the relevant administration. Ofcom also has the ability to pass issues to other administrations to investigate if interference originates from outside the UK.

7.52 Interference *between* satellite networks can often resolved by the operators involved. Where this is not possible, and the interference originates from satellites filed through the UK, we have the ability to investigate and (if necessary and appropriate) request the operator to stop interfering. For satellite networks filed with other administrations we can liaise with the other administrations in order to resolve the case.

Question 17: Are there any improvements we should consider in how we enable existing benefits to continue, whilst exploring sharing / new uses?

Other growing benefits

7.53 The following applications could provide growing consumer and citizen benefits in the future. However for the reasons discussed below, we propose that they do not need to be a particular focus for regulatory action, at least in the short to medium term.

Higher resolution broadcast TV content

7.54 Our assessment is that higher resolution broadcast TV content, including more high definition (HD) channels and the introduction of ultra-high definition (UHD) TV, can be delivered within existing spectrum allocations.

7.55 For Direct to Home satellite TV, we believe that 30 UHD channels, plus continued growth in the number of HD channels, could readily be accommodated within existing spectrum allocations.[68] This is based on the anticipated use of more efficient technologies (for example greater use of DVB-S2 and introduction of HEVC) and continued use of the orbital location that consumer satellite antennas currently point at (so they would not need re-pointing or upgrading). Our interactive analysis identifies the key variables and their sensitivity to demand and supply. Annex 5 sets out our analysis.

7.56 For contribution and distribution of broadcast content, there are more options for expanding capacity than DTH. This is because the earth stations used by broadcasters can operate to a range of orbital locations, in contrast to consumer DTH antenna which are fixed to a single orbital location. Consequently, broadcasters can use a number of different satellites at different orbital locations and at different frequencies.

7.57 Therefore, building on our analysis that DTH has sufficient capacity and can accommodate the move to UHD at a single orbital location, we believe that contribution and distribution of UHD content will also be possible within existing spectrum allocations, given the additional options for capacity open to them.

Satellite navigation and positioning

7.58 The benefits from satellite navigation and positioning will continue to grow with its use by more devices and more applications. The future introduction of the European Galileo satellite positioning network will help address the demand for increased accuracy (including in urban areas where fewer satellites are visible), but is not expected to have major new implications for spectrum allocations.

Machine-to-machine communications and the ‘Internet of things’

7.59 Machine-to-machine communications and the ‘Internet of things’ will continue to grow, and satellite communications could have a role for some applications. However, the capacity implications for most applications seem likely to be relatively small compared to growth in satellite broadband communications.

[68] In principle there would be enough capacity for all (>100) existing HD channels to transition to UHD, although at present we do not believe is this the most likely scenario.

7.60 Nonetheless, given that it is hard to predict future innovations in this sector, and the future role of satellites in the 'Internet of things' is relatively uncertain at present, we will keep this position under review.

Safety-related communications

7.61 Safety-related communications for **the global tracking of aircraft and for control of unmanned aircraft** are of growing importance.

7.62 The output from WRC-15 on both of these issues will now be considered by the International Civil Aviation Organisation (ICAO) and those responsible for aviation regulation in the UK, as the majority of work now lies mainly with those bodies. However, Ofcom will continue to monitor both items, as well as work on the Global Aeronautical Distress and Safety System (GADSS), to stay informed about this area and respond accordingly.

Question 18: Do you agree that the applications we identify do not need to be a particular focus for regulatory action in the short to medium term?

Annex 1

Responding to this consultation

How to respond

A1.1 Ofcom invites written views and comments on the issues raised in this document, to be made by **10 May 2016**.

A1.2 Ofcom strongly prefers to receive responses using the online web form at http://stakeholders.ofcom.org.uk/consultations/space-spectrum-strategy/howtorespond/ , as this helps us to process the responses quickly and efficiently. We would also be grateful if you could assist us by completing a response cover sheet (see Annex 3), to indicate whether or not there are confidentiality issues. This response coversheet is incorporated into the online web form questionnaire.

A1.3 For larger consultation responses - particularly those with supporting charts, tables or other data - please email SSSreview@ofcom.org.uk attaching your response in Microsoft Word format, together with a consultation response coversheet.

A1.4 Responses may alternatively be posted or faxed to the address below, marked with the title of the consultation.

Justin Moore
Spectrum Group
Riverside House
2A Southwark Bridge Road
London SE1 9HA

A1.5 Note that we do not need a hard copy in addition to an electronic version. Ofcom will acknowledge receipt of responses if they are submitted using the online web form but not otherwise.

A1.6 It would be helpful if your response could include direct answers to the questions asked in this document, which are listed together at Annex 4. It would also help if you can explain why you hold your views and how Ofcom's proposals would impact on you.

Further information

A1.7 If you want to discuss the issues and questions raised in this consultation, or need advice on the appropriate form of response, please contact Justin.moore@ofcom.org.uk.

Confidentiality

A1.8 We believe it is important for everyone interested in an issue to see the views expressed by consultation respondents. We will therefore usually publish all responses on our website, www.ofcom.org.uk, ideally on receipt. If you think your response should be kept confidential, can you please specify what part or whether all of your response should be kept confidential, and specify why. Please also place such parts in a separate annex.

A1.9 If someone asks us to keep part or all of a response confidential, we will treat this request seriously and will try to respect this. But sometimes we will need to publish all responses, including those that are marked as confidential, in order to meet legal obligations.

A1.10 Please also note that copyright and all other intellectual property in responses will be assumed to be licensed to Ofcom to use. Ofcom's approach on intellectual property rights is explained further on its website at http://www.ofcom.org.uk/terms-of-use/

Next steps

A1.11 Following the end of the consultation period, Ofcom intends to publish a statement in Q3/4 2016.

A1.12 Please note that you can register to receive free mail Updates alerting you to the publications of relevant Ofcom documents. For more details please see: http://www.ofcom.org.uk/email-updates/

Ofcom's consultation processes

A1.13 Ofcom seeks to ensure that responding to a consultation is easy as possible. For more information please see our consultation principles in Annex 2.

A1.14 If you have any comments or suggestions on how Ofcom conducts its consultations, please call our consultation helpdesk on 020 7981 3003 or e-mail us at consult@ofcom.org.uk . We would particularly welcome thoughts on how Ofcom could more effectively seek the views of those groups or individuals, such as small businesses or particular types of residential consumers, who are less likely to give their opinions through a formal consultation.

A1.15 If you would like to discuss these issues or Ofcom's consultation processes more generally you can alternatively contact the Secretary to the Corporation, who is Ofcom's consultation champion:

Secretary to the Corporation
Ofcom
Riverside House
2a Southwark Bridge Road
London SE1 9HA

Tel: 020 7981 3601

Email Graham.Howell@ofcom.org.uk

Annex 2

Ofcom's consultation principles

A2.1 Ofcom has published the following seven principles that it will follow for each public written consultation:

Before the consultation

A2.2 Where possible, we will hold informal talks with people and organisations before announcing a big consultation to find out whether we are thinking in the right direction. If we do not have enough time to do this, we will hold an open meeting to explain our proposals shortly after announcing the consultation.

During the consultation

A2.3 We will be clear about who we are consulting, why, on what questions and for how long.

A2.4 We will make the consultation document as short and simple as possible with a summary of no more than two pages. We will try to make it as easy as possible to give us a written response. If the consultation is complicated, we may provide a shortened Plain English Guide for smaller organisations or individuals who would otherwise not be able to spare the time to share their views.

A2.5 We will consult for up to 10 weeks depending on the potential impact of our proposals.

A2.6 A person within Ofcom will be in charge of making sure we follow our own guidelines and reach out to the largest number of people and organisations interested in the outcome of our decisions. Ofcom's 'Consultation Champion' will also be the main person to contact with views on the way we run our consultations.

A2.7 If we are not able to follow one of these principles, we will explain why.

After the consultation

A2.8 We think it is important for everyone interested in an issue to see the views of others during a consultation. We would usually publish all the responses we have received on our website. In our statement, we will give reasons for our decisions and will give an account of how the views of those concerned helped shape those decisions.

Annex 3

Consultation response cover sheet

A3.1 In the interests of transparency and good regulatory practice, we will publish all consultation responses in full on our website, www.ofcom.org.uk.

A3.2 We have produced a coversheet for responses (see below) and would be very grateful if you could send one with your response (this is incorporated into the online web form if you respond in this way). This will speed up our processing of responses, and help to maintain confidentiality where appropriate.

A3.3 The quality of consultation can be enhanced by publishing responses before the consultation period closes. In particular, this can help those individuals and organisations with limited resources or familiarity with the issues to respond in a more informed way. Therefore Ofcom would encourage respondents to complete their coversheet in a way that allows Ofcom to publish their responses upon receipt, rather than waiting until the consultation period has ended.

A3.4 We strongly prefer to receive responses via the online web form which incorporates the coversheet. If you are responding via email, post or fax you can download an electronic copy of this coversheet in Word or RTF format from the 'Consultations' section of our website at http://stakeholders.ofcom.org.uk/consultations/consultation-response-coversheet/.

A3.5 Please put any parts of your response you consider should be kept confidential in a separate annex to your response and include your reasons why this part of your response should not be published. This can include information such as your personal background and experience. If you want your name, address, other contact details, or job title to remain confidential, please provide them in your cover sheet only, so that we don't have to edit your response.

Cover sheet for response to an Ofcom consultation

BASIC DETAILS

Consultation title:

To (Ofcom contact):

Name of respondent:

Representing (self or organisation/s):

Address (if not received by email):

CONFIDENTIALITY

Please tick below what part of your response you consider is confidential, giving your reasons why

Nothing	☐	Name/contact details/job title	☐
Whole response	☐	Organisation	☐
Part of the response	☐	If there is no separate annex, which parts?	

If you want part of your response, your name or your organisation not to be published, can Ofcom still publish a reference to the contents of your response (including, for any confidential parts, a general summary that does not disclose the specific information or enable you to be identified)?

DECLARATION

I confirm that the correspondence supplied with this cover sheet is a formal consultation response that Ofcom can publish. However, in supplying this response, I understand that Ofcom may need to publish all responses, including those which are marked as confidential, in order to meet legal obligations. If I have sent my response by email, Ofcom can disregard any standard e-mail text about not disclosing email contents and attachments.

Ofcom seeks to publish responses on receipt. If your response is non-confidential (in whole or in part), and you would prefer us to publish your response only once the consultation has ended, please tick here. ☐

Name Signed (if hard copy)

Annex 4

Consultation questions

Question 1: How useful is the interactive data that we have provided on our website and why? How can the presentation and interactivity of the data be improved? How frequently would it be useful for us to update the information and why?

Question 2: Do you agree with the industry and technology trends we have identified for the satellite sector? Are there other trends that could have implications for spectrum use?

Question 3: Do you agree with the application specific trends we have identified for the satellite sector? Are there other trends that could have implications for spectrum use?

Question 4: Do you agree with the industry and technology trends we have identified for the space science sector? Are there other trends that could have implications for spectrum use?

Question 5: Do you agree with the application specific trends we have identified for the space science sector? Are there other trends that could have implications for spectrum use?

Question 6: Do you agree with the applications we have identified as having particular potential for growth in consumer and citizen benefits?

Question 7: Do you agree with the three priorities that we have proposed for our strategy? Are there other priorities that are as important, or more important, for citizens and consumers and why?

Question 8: Are there other areas where spectrum liberalisation could enable better satellite broadband services and what specific actions should we be considering?

Question 9: Do you agree that existing bands are likely to provide sufficient capacity for considerable growth in satellite broadband and that we do not need to prioritise the identification of new bands? Do you have any comments on the analysis we have undertaken of supply and demand?

Question 10: To what extent does the proliferation of filings for ‘paper satellites’ create costs or barriers that hinder the provision of satellite services to UK citizens and consumers?

Question 11: Are there other actions we should be considering that could enable greater benefits from satellite broadband?

Question 12: Do you agree that existing bands are likely to provide sufficient capacity for considerable growth in earth observation data downlink and that we do not need to prioritise the identification of new bands? Do you have any comments on the analysis we have undertaken of supply and demand scenarios?

Question 13: What other specific actions should we be considering to facilitate earth observation data downlink?

Question 14: To what extent will access to suitable spectrum for TT&C enable greater use of small satellites and why? Do you agree with the specific actions we have identified and what else should we be considering?

Question 15: What other actions should we be considering to support long term predictability of access to sensing bands?

Question 16: Are there other actions we should be considering that could enable greater benefits from earth observation?

Question 17: Are there any improvements we should consider in how we enable existing benefits to continue, whilst exploring sharing / new uses?

Question 18: Do you agree that the applications we identify do not need to be a particular focus for regulatory action in the short to medium term?

Annex 5

Supply and demand analysis details

Overview

A5.1 This annex provides details of our approach, and the underlying assumptions for our high level modelling of demand and capacity/supply. We have focused on the following applications, where more information and data points on which to base our approach, are available:

- Direct to Home TV
- Mobile and fixed broadband
- Earth observation imagery

A5.2 We have developed simplified models which take account of the key variables affecting demand and capacity, building on the industry trends we have identified in section 6. The analysis presents a number of scenarios, but does not aim to provide specific forecasts. We have developed it to inform our strategy alongside our intelligence of the industry, and the responses to the CFI.

A5.3 The interactive data published alongside this document allows stakeholders to further analyse the sensitivity of demand and supply to a number of key variables. We welcome stakeholders' comments and feedback with regards to our assumptions and our approach.

Direct to Home TV

A5.4 In section 6 we have highlighted the major demand and supply drivers for DTH TV, in particular the increasing demand for higher resolution broadcast content (HD, UHD) against the improvements in compression rates and modulation.

A5.5 Our assumptions with regards to demand are as follows:

- The number of SD channels will decline from 700 today to 620 in 2025 and the required bit rate will remain flat throughout the period under analysis at 3Mbit/s. We assume broadcasters will continue simulcasting of SD and HD channels until 2019 and we have assumed a 2% year on year decline, in SD channels from 2020 onward. This reflects the fact that some SD channels might not move to HD and could potentially migrate to other platforms (e.g. IPTV). From a required bit rate perspective we have not assumed any improvement in the compression of SD content over time as more focus will be on improving HD and UHD compression.
- The number of HD channels will grow from 115 today to 187 in 2025. This is driven by an assumed 5% year on year growth in the number of channels broadcasted in HD from 2015 to 2025. We have recently seen a slower year on year growth in the number of HD channels from 30% between 2012[69] and 2013[70]

[69] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr13/icmr/ICMR_2013_final.pdf

to 1% between 2013 and 2014[71]. With the cessation of SD simulcasting we believe we could see an increase in the growth rate of HD channels from 2015 to 5% year on year. This growth is more modest than in the past, as the technology matures. We assume that the required bit rate for HD channels will decline from 8Mbit/s today to 5Mbit/s in 2020 and will thereafter remain stable until 2025.

- We assume UHD content will start being broadcasted by 2017 with 20 channels broadcasting in UHD by 2020, growing to 30 by 2025. Our figures are driven by the higher cost involved in broadcasting UHD content and the assumption that the demand for UHD 4K TV might be limited to specific types of content such as sport and high quality movie channels. We have assumed 20Mbit/s will be required to support UHD TV from 2020 to 2025.

- We have also considered a second scenario with a more significant and faster decline in SD channels being broadcasted as they move to other platforms. This might bring the total number of SD channels down from 700 today to 350 in 2025 with the number of HD and UHD channels as above.

A5.6 On the basis of these figures we have estimated total DTH TV demand to either grow from 3Gbit/s today to 3.4Gbit/s in 2025, or in the case of the faster decline in SD channels, to decline from the 3Gbit/s today to 2.6Gbit/s in 2025.

A5.7 Table 5 below provides an overview of our assumptions. Our online interactive data allows additional sensitivity analysis, with regards to number of channels and required bit rates, to be carried out.

Table 5: DTH TV demand assumptions

Scenario 1	**2015[72]**	**2020**	**2025**
SD channels	700[73]	686	620
SD required throughput	*3 Mbit/s*	*3 Mbit/s*	*3 Mbit/s*
HD channels	115[73]	147	187
HD required throughput	*8 Mbit/s*	*5 Mbit/s*	*5 Mbit/s*
UHD channels	0	20	30
UHD required throughput		20Mbit/s	20Mbit/s
Total required throughput	**3 Gbit/s**	**3.2 Gbit/s**	**3.4 Gbit/s**

[70] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr14/icmr/ICMR_2014.pdf
[71] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/icmr15/icmr_2015.pdf
[72] For the purpose of this data analysis we have used data from February 2016 to represent the market structure in 2015.
[73] This is based on data from KingOfSat, extracted on 4th February 2016. http://en.kingofsat.net/pos-28.2E.php

Scenario 2	**2015**	**2020**	**2025**
SD channels	700	462	350
SD required throughput	*3 Mbit/s*	*3 Mbit/s*	*3 Mbit/s*
HD channels	115	147	187
HD required throughput	*8 Mbit/s*	*5 Mbit/s*	*5 Mbit/s*
UHD channels	0	20	30
UHD required throughput		20 Mbit/s	20 Mbit/s
Total required throughput	**3 Gbit/s**	**2.5 Gbit/s**	**2.6 Gbit/s**

A5.8 Our assumptions with regards to supply are as follows:

- Satellites and transponders: The vast majority of DTH TV content in the UK is delivered via three SES Astra satellites (2E,2F,2G) at the same orbital location (28.2 East). Currently the three satellites at this location have a total of 104 x 27MHz and 12 x 36MHz transponders (TPEs) that can be used simultaneously, with a high degree of redundancy provided. In assessing capacity, we have assumed a transition over time of modulation from QPSK (DVB-S) to 16QAM (DVB-S2X). Table 6 provides an overview of our assumptions with regards to the capacity available at 28.2East.

Table 6: DTH TV capacity assumptions

	2015		**2020**		**2025**	
	QPSK (DVB-S)		8QAM (DVB-S2)		16QAM (DVB-S2X)	
	27MHz	36MHz	27MHz	36MHz	27MHz	36MHz
TPE	104	12	104	12	104	12
MHz	27	36	27	36	27	36
Roll off	1.2	1.2	1.1	1.1	1.05	1.05
Symbol Rate (Mbit/s)	22.5	30	24.5	32.7	25.7	34.3
Forward Error Correction rate	5/6	5/6	5/6	5/6	5/6	5/6

Reed-Solomon error correction rate	188/204	188/204	188/204	188/204	188/204	188/204
Modulation coefficient	2	2	3	3	4	4
Throughput per transponder (Mbit/s)	34.6	46.1	56.6	75.4	79.0	105.3
Total supply (Mbit/s)	3594.1	552.9	5881.3	904.8	8215.1	1263.9
Supply Sub-Total (Gbit/s)	**3.6**	**0.6**	**5.9**	**0.9**	**8.2**	**1.3**
Total supply (Gbit/s)	**4.1**		**6.8**		**9.5**	

A5.9 On the basis of the above capacity assumptions we believe that the capacity provided by the three satellites at 28.2E will be sufficient to meet the demand in both the scenarios we have considered. Table 7 below provides a summary of our demand and capacity analysis.

Table 7: Summary of DTH demand and capacity scenarios

	2015	2020	2025
Demand – scenario 1	3 Gbit/s	3.2 Gbit/s	3.4 Gbit/s
Demand – scenario 2	3 Gbit/s	2.5 Gbit/s	2.6 Gbit/s
Capacity	4.1 Gbit/s	6.8 Gbit/s	9.5 Gbit/s

Fixed and mobile broadband

A5.10 We have developed future scenarios for fixed and mobile broadband to provide an illustration of the potential capacity that could be delivered by satellites if there were sufficient demand from consumers. In particular we have considered the capacity that could in principle be delivered from a number of GSO HTS satellites in Ka band in order to meet consumer demand.

A5.11 The interactive data analysis, published alongside this document, allows stakeholders to analyse demand and supply for both fixed and mobile broadband by flexing key supply parameters such as contention ratio, satellite capacity driven by modulation and number of satellites.

A5.12 Our assumptions with regard to fixed broadband demand are as follows:

- Number of households/premises: As identified in section 6, satellite might play a growing role in providing fixed broadband to hard-to-reach areas. We have considered scenarios where satellite broadband is provided to around 0.7% of UK premises by 2020 and 1% of UK premises by 2025, these figures represent a 35% and 50% of the current total 2% of UK premises that are connected by fixed lines and are currently unable to support speeds of 2 Mbit/s[74].

- Speed: we have defined our 2020 scenario consistent with the stated ambition of the broadband universal service ambition (10 Mbit/s), with our 2025 scenario doubling that to 20 Mbit/s.

- Contention ratio: we have assumed a contention ratio (the ratio between the peak rate available to end users and the provisioned capacity) of 20:1. It is possible that some satellite broadband services may offer a greater contention ratio than this (perhaps 50:1). However we have chosen an assumption which we believe is closer to terrestrial fixed broadband services.

A5.13 Our modelling of fixed and mobile broadband starts from 2020, given the limited evidence we have on current satellite broadband use. Table 8 provides an overview of our assumptions and approach to calculate fixed broadband demand.

Table 8: Fixed broadband demand assumptions

	2020	2025
Number of served premises	200,751	286,787
Required throughput per premise Mbit/s	10	20
Total contended demand Mbit/s	2,007,510	5,735,742
Total contended demand Gbit/s	2,008	5,736
Contention ratio	20:1	20:1
Total demand for broadband via satellite Gbit/s	100.4	286.8

A5.14 Our assumptions with regard to mobile broadband demand are as follows:

[74] We assume that there are 286,787 UK premises, which is a figure derived from data published with the Connected Nations Report 2015: http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2015/downloads/connected_nations2015.pdf

- Our focus has been primarily on analysing potential demand for satellite broadband from passengers on aircrafts, since the volume of passengers on aircrafts travelling to and from the UK is about five times greater than the number of passengers on ships).[75]

- Planes and passengers: we have considered a scenario where all long haul flights travelling over the UK offer broadband services to all their passengers (e.g. via an inflight Wi-Fi service). Today there are around 600 planes over the UK at peak time[76] and we have assumed that in 2020 around 25% (150) of these will be long haul, based on CAA data.[77] We assume that the number of flights offering broadband will increase by a third (i.e. to 200) by 2025.

- Service take up and speed: we have considered the take up of in-flight mobile broadband / Wi-Fi by passengers to be along the lines of current smartphone penetration in the UK (70% of mobile base[78]), going up to 80% in 2020 and 90% in 2025. We have assumed speed provided to be along the lines of terrestrial mobile, where 2Mbit/s is currently considered the minimum speed to stream video over mobile. We have assumed this figure will grow to 5Mbit/s in 2020 and 10Mbit/s in 2025.

Table 9: Mobile broadband demand assumptions

	2020	2025
Number of long haul flights over the UK at any time	150	200
Average passengers per aircraft	250	250
Required throughput per passenger (Mbit/s)	5	10
Potential number of users	37,500	50,000
Service take up	80%	90%

[75] There were 247m air passengers in year Q2 2015, compared to 46m sea passengers (excluding river ferries) in 2014. Department of Transport Sea Passenger Statistics 2014 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/475680/final-sea-passenger-statistics-2014.pdf.and Civil Aviation Authority, Aviation Trends Q2 2015 https://www.caa.co.uk/uploadedFiles/CAA/Content/Standard_Content/Data_and_analysis/Analysis_reports/Aviation_trends/Aviation%20Trends%202015%20Q2.pdf
[76] Viewing of banner on NATS website on 24th February, http://www.nats.aero/
[77] Civil Aviation Authority, Aviation Trends Q2 2015, Note: the proportion of passengers taking long haul flights from UK airport is taken as a proxy for the number of aircraft in UK airspace that are on a long-haul journey.
[78] Ofcom Technology Tracker Wave 2 2015 http://stakeholders.ofcom.org.uk/binaries/research/statistics/2015oct/Ofcom_Technology_Tracker_Half_2_2015_UK_data_tables.pdf

Aviation mobile data users	30,000	45,000
Contention Ratio	20:1	20:1
Total mobile broadband demand for aviation (Gbit/s)	**7.5**	**22.5**
Estimated ratio aircraft v ships passengers	5	5
Total mobile broadband demand for ships (Gbit/s)	**1.5**	**4.5**
Total mobile broadband demand (Gbit/s)	**9.0**	**27.0**

Table 10: Summary of mobile and fixed broadband demand

	2020	**2025**
Total fixed broadband demand (Gbit/s)	100.4	286.8
Total mobile broadband demand (Gbit/s)	9.0	27.0
Total fixed and mobile broadband demand (Gbit/s)	**109.4**	**313.8**

A5.15 Our assumptions with regards to total supply to address both fixed and mobile broadband are as follows:

- Satellites: we have modelled a total of 10 Ka band HTS satellites by 2020 and 22 by 2025. In principle the orbital arc visible from the UK could support 42 GSO satellites and therefore our 2025 assumption represents use of about half of the usable orbital slots.

- Reuse: we have assumed 4 colour and 4 beams over UK in line with current beam sizes on high throughput Ka band satellites

- Modulation: we have assumed 16QAM in 2020 and 32 QAM in 2025
- Spectrum available: we have assumed 2GHz of Ka band to be available. This is based on the assumption, that in the Earth-to space direction, there is 2.5 GHz available in the band 27.5 – 30 GHz and that the 29.5 – 30 GHz portion of the band will be used principally by user terminals for the return link. 2.5GHz could possibly start to be used from 2025 if gateway provision, currently in Ka band, moves to Q and V band on next generation satellites. However, it may take longer for the majority of satellites to migrate and therefore we have assumed 2 GHz for 2025.

We have not considered the possible impact of multiple beams (HTS) being introduced in Ku band

Table 11: Fixed and mobile broadband supply assumptions

	2020	**2025**
	16QAM	32QAM
Roll off	1.1	1.05
Available spectrum (MHz)	2000	2000
Symbol Rate (Msps)	1818.2	1904.8
Forward Error Correction rate	5/6	5/6
Reed-Solomon error correction rate	188/204	188/204
Modulation coefficient	4	5
Available throughput per polarization (Mbit/s)	5585	7314
Available throughput per polarization (Gbit/s)	5.59	7.31
Available throughput (dual polarity) (Gbit/s)	**11.17**	**14.63**
Number of satellites	10	22
Total capacity Gbit/s	**111.7**	**321.8**

A5.16 In the scenarios modelled there is sufficient capacity to meet demand. If demand were to grow over and above the values we have assumed, more satellites could be deployed in the orbital arc visible from the UK.

Table 12: Summary of fixed and mobile broadband demand and supply

	2020	**2025**
Fixed demand (Gbit/s)	100	287
Mobile demand (Gbit/s)	9	27
Total demand (Gbit/s)	**109**	**314**
Total supply (Gbit/s)	**111.7**	**321.8**

A5.17 The interactive analysis we publish alongside this document will allow stakeholders to flex key variables driving capacity, such as the number of satellites, the contention ratio, the speed required and the number of users.

Earth observation

A5.18 In section 6, we identified several application and industry trends that are contributing to a projected rapid growth in demand for data generated by Earth observation missions. These are:

- Greater commercialisation of Earth observation data
- Ability to deliver more frequent observations
- Higher resolution imagery
- Significant growth in deployment of small satellites.

A5.19 Although the number of earth observation satellites and the amount of data sent from satellites to Earth Stations are projected to grow, we have assumed that earth observation operators are able to continue to share the available spectrum by co-ordinating their satellite networks. The implication of this assumption is that it is only necessary to calculate the amount of data generated by one satellite in order to estimate the data downlink spectrum requirement.

A5.20 We have analysed a high-demand scenario where the satellite holds two optical imaging instruments gathering two types of image data: panchromatic (greyscale), and multispectral (multicolour). Our approach is to calculate how much data can be generated by each instrument per day by calculating how many pixels are gathered daily. We do this by calculating the area of the Earth its beams will cover in a day, and dividing this by the resolution of the images. We then convert the number of pixels into bits per second by making assumptions about the number of bits of data needed for each pixel, as well as assumptions about the proportion of time that the instruments will be gathering data.

A5.21 Our analysis assumes that the satellite is capturing data during a proportion of the day but that it can spread the downlink of this data over the full day. This reduces the required data rate (compared to a real time downlink) and relies on in-orbit storage of data, plus either a large network of earth stations or the relay of data via a geostationary relay satellite.

A5.22 It is worth noting that there is no “typical” satellite in the Earth Observation sector. Rather, each satellite has its own specific characteristics and carries its own specific instruments[79]. The interactive data published alongside this document allows stakeholders to further analyse the sensitivity of demand and supply to some key variables.

A5.23 Our assumptions with regards to earth observation demand are as follows:

- Resolution. We have assumed the resolution available on panchromatic images will improve to meet new limits laid down in US legislation. For multispectral images, we assume that 2015 images have the same resolution (31 cm) as products available from Worldview-3[80], and that in 2020 the images will have the same resolution (25 cm) as available in Worldview-4[81]. This change actually reflects deterioration in the resolution of the multispectral images, which we believe is not likely to continue beyond 2015. To compensate for this, we have assumed that the multispectral resolution for 2025 will be identical to 2015.

- Swathe Width. We assume that this will be the swathe width used by Worldview-3 in 2015. To calculate the rate of change, we have looked at the difference in swathe width between Worldview-3, which was launched in 2014, and Worldview-4, which is to be launched in 2016. This corresponds to an 11% improvement in two years. We have assumed that this rate of change will continue until 2020, after which the rate of improvement every two years will fall to 4%.

- Distance travelled over Earth per day. This is estimated by using information given by Worldview about the number of orbits per day performed by each satellite. Although the number of orbits per day will grow from 14.8 to 15 from Worldview-3 to Worldview-4, we do not believe this number will grow further because orbits per day is said to be dependent on the required resolution, and this value is not expected to change from 2020.

- Bits per pixel post compression. This is based on information that is publicly available about compression instruments[82] used in Sentinel’s optical Earth Observation programme. We assume there will be improvements in compression technology over time.

- Proportion of time instruments are in use. This is assumed to increase over time as demand for optical Earth Observation data grows. We understand that Earth Observation is often used for use cases such as disaster

[79] For the purposes of this analysis, we have sought to model a high capacity scenario and have used some characteristics of the Worldview-3 satellite, which was launched in 2014. This satellite currently offers the highest resolution images that are commercially available. In 2016, it will be complemented by Worldview-4, which has similar characteristics.

[80] http://www.spaceimagingme.com/downloads/sensors/datasheets/DG_WorldView3_DS_2014.pdf

[81] http://www.satimagingcorp.com/satellite-sensors/geoeye-2/

[82] http://www.esa.int/Our_Activities/Space_Engineering_Technology/Onboard_Data_Processing/CCSDS_Image_Data_Compression_ASIC

monitoring and precision agriculture, but that emerging use cases such as asset tracking and security applications may lead satellite operators to use their Earth Observation instruments for longer portions of the day, including during times when the satellite will pass over oceans.

A5.24 The following table provides an overview of the demand assumptions for a high-performance panchromatic instrument

Table 13: Panchromatic optical Earth Observation demand assumptions

	2015	2020	2025
Resolution (m)	0.31	0.25	0.25
Resolution (m^2)	0.1	0.06	0.06
Swathe Width (km)	13.1	16.69	18.05
Orbits per day	14.8	15	15
Total area captured per second (km^2)	90	116	126
Total number of pixels captured per second (millions)	936	1,858	2,010
Bits per pixel after compression	8	6	4
Proportion of time instrument is turned on	30%	40%	50%
Demand per instrument (Mbit/s)	2,246	4,459	4,019
Demand per instrument (Gbit/s)	**2.24**	**4.46**	**4.02**

A5.25 The table below provides an overview of the demand assumptions for a high-performance multispectral instrument

Table 14: Multispectral optical Earth Observation demand assumptions

	2015	2020	2025
Resolution (m)	1.24	1.36	1.24
Resolution (m^2)	1.54	1.85	1.54
Swathe Width (km)	13.1	16.69	18.05
Orbits per day	14.8	15	15
Total area captured per second (km^2)	90	116	126

Total number of pixels captured per second (millions)	58	63	82
Bits per pixel after compression	8	6	4
Proportion of time instrument is turned on	30%	40%	50%
Demand per instrument (Mbit/s)	140	151	163
Demand per instrument (Gbit/s)	**0.14**	**0.15**	**0.16**
Total demand panchromatic and multispectral (Gbit/s)	**2.38**	**4.61**	**4.18**

A5.26 Our assumptions with regards to total capacity for data transmissions from EO satellites to Earth Stations are as follows:

- The growth in capacity is driven by the adoption of more advanced modulation systems in the coming decade. Specifically, we assume that QPSK is currently used but that this will be replaced by 16QAM in 2020 and 32QAM in 2025.
- The allocation of 375 MHz in the X Band and 1500 MHz in the Ka Band to the Earth Exploration-Satellite (space-to-Earth) service at 8025-8400MHz and 25.5-27 GHz will be maintained.

Table 15: Optical Earth Observation supply assumptions

	2015	**2020**	**2025**
Modulation	QPSK	16 QAM	32 QAM
X Band spectrum (MHz)	375	375	375
X Band capacity (Gbit/s)	0.48	0.96	1.2
Ka Band spectrum (MHz)	1500	1500	1500
Ka Band capacity (Gbit/s)	1.92	3.84	4.8
Total capacity (Gbit/s)	2.4	4.8	6

Table 16: Summary of Earth Observation supply and demand

	2015	**2020**	**2025**
Total demand from single satellite (Gbit/s)	**2.38**	**4.61**	**4.18**
Total capacity (Gbit/s)	2.4	4.80	6.00

A5.27 Our modelling indicates that in the scenarios we have considered, there would be sufficient capacity to downlink the optical imagery data being generated by a high resolution earth observation satellite. In 2015 and 2020 there is only just enough capacity, but by 2025 there would be more than enough capacity. This finding is driven by our assumptions of increasing demand being offset over time by improvements in compression and adoption of more spectrally efficient modulation techniques.

Annex 6

Glossary

AMS(R)S	Aeronautical Mobile Satellite (Route) Service. A particular type of AMSS reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes
AMSS	Aeronautical Mobile Satellite Service. A particular type of MSS for which the earth stations are located on board aircraft.
BSS	Broadcasting Satellite Service. One-way transmission of high-power broadcast signals by GSO satellites directly to consumers, who receive the signals on locally installed antenna equipment (e.g. satellite dishes).
C-band	Spectrum frequencies commonly in the ranges around 6 GHz (Earth-to-space) and around 4 GHz (space-to-Earth)
CEPT	European Conference of Postal and Telecommunications Administrations
CFI	Call for Input
CGC	Complementary Ground Component. A terrestrial network which forms as integral part of a MSS system and uses the same frequencies, in the same direction as the satellite and which does not increase the spectrum demands of the MSS system.
DTH	Direct to Home. Involves the reception of television signals directly from satellites.
Earth station	A station located either on the earth's surface or within the major portion of the Earth's atmosphere and intended for radio communication with one or more satellites or space stations
EESS	Earth Exploration Satellite Service. A satellite radiocommunication service which obtains information relating to the characteristics of the Earth and its natural phenomena from active or passive sensors on the satellite, and distributes this information to earth stations.
EO	Earth Observation
ESIM	Earth Station In Motion (see ESOMP)
ESOMP	Earth Stations on Mobile Platform. A satellite earth station mounted on a mobile platform such as an aircraft, ship, train or road vehicle, intended for communication with one or more

	satellites.
Frequency band	A defined range of frequencies that may be allocated for a particular radio service, or shared between radio services
FSS	Fixed Satellite Service. Two-way communication links between earth stations, usually at fixed locations, and one or more satellites.
Galileo	Europe's satellite navigation system (similar to GPS) under civilian control
GHz	Gigahertz. A unit of frequency of one billion cycles per second.
GLONASS	GLObal NAvigation Satellite System - A satellite-based radio navigation system run by the Russian Ministry of Defence.
GMDSS	Global Maritime Distress and Safety System. A particular system operating under the MMSS providing communication services to people in distress.
GNSS	Global Navigation Satellite System (examples include GPS or Galileo)
GPS	Global Positioning System. A space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.
GSO	Geostationary Satellite Orbit. The orbit of a satellite whose circular and direct orbit lies in the plane of the Earth's equator and which remains fixed relative to the Earth's surface.
HAPS	High Altitude Platforms are vehicles - for example manned or unmanned aeroplanes, balloons, or airships - situated in the stratosphere used for the delivery of wireless communications.
HEVC	High Efficiency Video Coding - a video compression technology being used for ultra high definition video services.
HTS	High Throughput Satellite. Satellites that typically employ frequency re-use techniques to increase their overall throughput.
IMT	International Mobile Telecommunications. The ITU term that encompasses 3G, 4G and 5G wireless broadband systems.
IPTV	Internet Protocol Television. The term used for television and/or video signals that are delivered to subscribers or viewers using internet protocol (IP), the technology that is generally used to access the internet.

HD	High Definition
ISS	Inter Satellite Service. Two-way transmission of signals between two or more satellites. Typically these are used for non-GSO constellations of satellites to relay transmissions between individual satellites.
ITU	International Telecommunications Union - part of the United Nations with a membership of 193 countries and over 700 private-sector entities and academic institutions. ITU is headquartered in Geneva, Switzerland.
ITU-R	International Telecommunications Union Radiocommunication Sector
ITU-R Region 1	Article 5 of the ITU Radio Regulations divides the world into three regions for the allocation of frequencies. Region 1 includes Europe, Africa, parts of the Middle East, the former Soviet Union and Mongolia.
Ka band	Spectrum frequencies commonly in the ranges around 30 GHz (Earth-to-space) and 18 GHz (space-to-Earth)
Ku band	Spectrum frequencies commonly in the ranges around 14 GHz (Earth-to-space) and 11 GHz (space-to-Earth)
L-band	Spectrum frequencies commonly in the ranges around 1.5 GHz (space-to-Earth and Earth-to-space)
LEO	Low Earth Orbit. LEO satellites orbit the earth at heights between typically a few hundred kilometres to one or two thousand kilometres above the earth's surface.
M2M	Machine to Machine refers to technologies that allow both wireless and wired systems to communicate with other devices of the same type. M2M is a broad term as it does not pinpoint specific wireless or wired networking.
MEO	Medium Earth Orbit. MEO satellites orbit the earth at heights of around 10,000 km above the Earth's surface.
MetSat service	Meteorological Satellite Service. A type of earth exploration-satellite service for meteorological purposes.
MHz	Megahertz. A unit of frequency of one million cycles per second.
MMSS	Maritime Mobile Satellite Service. A particular type of MSS for which user terminals are located on board ships.
MSS	Mobile Satellite Service. Two-way communication links between portable user terminals and one or more satellites.

non-GSO	Non-geostationary satellite orbit
Ofcom	Independent regulator and competition authority for the UK communications industries
Orbital arc	An imaginary line tracing all positions along a given orbit
Orbital separation	The angular separation between two satellites on a given orbit
Orbital slots	The orbital position of satellites, typically on the geostationary satellite orbit
PES	Permanent Earth Station
QoS	Quality of service is the overall performance of a network, particularly the performance seen by the users of the network.
Radio Spectrum	The portion of the electromagnetic spectrum below 3000 GHz used for radiocommunications
RAS	Radio Astronomy Service. The ground based reception of naturally occurring emissions in order to research astrophysics and cosmology. This service is typically used in the study of celestial bodies such as pulsars, the formation of new stars, the properties of interstellar gases and plasmas, solar activity and microwave background radiation, the study of invisible mass and energy, and the expansion of the Universe.
RED	Radio Equipment Directive
RNSS	Radionavigation Satellite Service. One-way transmission of signals from constellations of satellites towards the Earth. The coded and time-stamped signals are used to determine the position and velocity of receive-only terminals on the Earth and to synchronise other devices to a single time reference. GPS and Galileo operate under this service.
ROES	Receive-Only Earth Station. A satellite earth station which receives radio signals but does not transmit.
RR	Radio Regulations
SAR	Synthetic Aperture Radar is used for creating radar images by transmitting a high power radio signal and analysing the echo.
S-band	Spectrum frequencies commonly in the ranges around 2 GHz (space-to-Earth and Earth-to-space)
SD	Standard Definition

SKA	Square Kilometre Array. An international project to build the world's most powerful radio astronomy sites, located in Australia and South Africa, with its headquarters based at Jodrell Bank observatory in the UK.
SMOS	Soil Moisture and Ocean Salinity
SMS	Spectrum Management Strategy, published by Ofcom on 30 April 2014
SRS	Space Research Service. A service for studying the physical characteristics of other celestial bodies including planets.
Teleport	A physical site usually owned by a single company where a relatively large number of earth stations are co-located
TES	Transportable Earth Station
TT&C	Telemetry, Telecommand and Control. Used in both satellite and space science communications where links are used to monitor data from a satellite on its health and functioning (telemetry); track the location of the satellite (tracking); and send commands from the ground to the satellite to satisfy operational mission requirements or to respond to emergency conditions (command).
UAVs	Unmanned Aerial Vehicle
UHD	Ultra High Definition
UK2	Except by special agreement having the approval of the NFPG this frequency band, or the allocation to this radio service, is reserved exclusively for military use
VSAT	Very Small Aperture Terminal. A satellite earth station equipped with an antenna of relatively small size.
WRC	World Radiocommunication Conference. The WRC reviews and revises the Radio Regulations. They are held every three to four years. The last three conferences were held in 2003, 2007 and 2012. The next WRC will be held in Geneva in November 2015 and is referred to as WRC-15.
xDSL	Refers collectively to all types of digital subscriber lines, the two main categories being Asymmetric DSL (ADSL) and Symmetric DSL (SDSL). Two other types of xDSL technologies are High-data-rate DSL (HDSL) and Very high data rate DSL (VDSL).