Ofcom Spectrum Advisory Board

Annual Report 2014 - 2015

Publication date: 21 September 2015

Contents

Section 1

Message from Ofcom's Chairman

Ofcom's Spectrum Advisory Board has been an invaluable source of advice for eleven years. It raises our sights from immediate spectrum issues and informs long term planning with real salience for the sector and the economy as a whole.

A communications revolution is underway; superfast broadband services and smartphones and tablets have changed dramatically the way we communicate. Expert advice, of the kind OSAB supplies, helps to ensure Ofcom's planning and regulatory framework responds to this change. The expertise of the Committee's diverse membership helps to anticipate problems across a wide ranging market and ensure sensible outcomes.

OSAB meetings are always well attended and the lively discussions are characteristic of the personal enthusiasm of the members. We are grateful for their support.

I am delighted that David Meyer has agreed to serve a further three years as Chairman of OSAB and look forward to a further year of fruitful engagement with him and his Committee

Dame Patricia Hodgson

Chairman of Ofcom

Section 2

Foreword by OSAB's Chairman

The Ofcom Spectrum Advisory Board (OSAB) is pleased to present its eleventh annual report and my fifth as its Chairman.

In this last year OSAB has offered insight and advice to Ofcom on a number of issues which have predominantly related to the use and management of spectrum. Subjects discussed by OSAB included issues related to planning the long-term use of ultra-high frequency (UHF) spectrum, technology developments in the core and access networks and the evolution of mobile services.

This year Robin Foster stepped down from the Committee and I would like to express my thanks for the contribution he made to OSAB during his term of office.

OSAB meetings are always characterised by the diverse knowledge and the passion for their subject which members bring to its meetings. Its meetings are always attended by senior members of Ofcom who also actively engage in the debates. Chairing OSAB meetings is a genuine privilege as well as a pleasure. I am most grateful to members, and to Ofcom staff (especially the secretary) for making the Chairman's job so easy.

OSAB is embarking on its twelfth year with unabated enthusiasm.

David Meyer

Chairman, Ofcom Spectrum Advisory Board

Section 3

Introduction

Background

4.1 The Ofcom Spectrum Advisory Board (OSAB) was established on 19 May 2004 to provide independent advice to Ofcom on strategic spectrum management issues. OSAB provides Ofcom with:

- A rapid way to test new ideas across a wide range of experts;
- A means of identifying issues that are beyond Ofcom's regulatory "headlights";
- A demonstration of Ofcom's commitment to consult in an open and collaborative manner; and
- A mechanism to help reach an agreed industry view of difficult and contentious issues through the hosting of open fora.

Annual report

4.2 This document reports on OSAB's eleventh year. It is intended to summarise selected discussions throughout the year and its content is based on published minutes of OSAB meetings.

Terms of reference

4.3 In 2008 the terms of reference for OSAB were revisited. Ofcom and OSAB agreed that although OSAB's initial role had been to provide advice to Ofcom on spectrum-related matters; it was increasingly difficult to consider spectrum-related matters in isolation in a converging world.

4.4 Hence it was decided that OSAB's remit should be broadened to include all future communication architectures, access methods, physical layer technologies, spectrum issues, services and applications. OSAB would be responsible for high level and longer term vision and not for detailed assessment of different approaches, standard setting or consensus building amongst industry. However, it would not involve itself with content matters.

Membership

4.5 The membership of OSAB is reviewed on an annual basis. This year Robin Foster resigned from the Committee. David Meyer, Linda Doyle and Gavin Young all accepted a three year extension to their current term of office.

4.6 Details of OSAB membership including the length of tenure are at Annex 2.

Work Programme

4.7 OSAB is responsible for agreeing its own work programme. During this year a range of topics was discussed, predominantly related to use and management of spectrum. These topics are broadly indicative of the key themes that OSAB, its members and many in the wider community have been considering over the past 12 months. We have organised the topics into three broad categories:

- Planning the long-term use of ultra-high frequency (UHF) spectrum;
- Technology developments in the core and access networks; and
- The evolution of mobile services.

4.8 OSAB meets 4-5 times a year and holds an annual workshop where a whole day is devoted to a particular issue. This year the workshop considered ways in which to predict and measure coverage for mobile services.

The Year Ahead

4.9 OSAB sets its agenda from meeting to meeting depending on progress made in particular areas, time available and topics arising. It deliberately does not plan a year ahead to allow for flexibility and responsiveness.

Further Information

4.10 For further information on the work of the Ofcom Spectrum Advisory Board, please contact the OSAB Secretary:

Mr Paul Rogers
Ofcom
Riverside House
2a Southwark Bridge Road
London SE1 9HA

Tel: 020 7783 4031

E-mail: paul.rogers@ofcom.org.uk

Or visit the OSAB website at www.osab.org.uk

Section 4

Topics considered during the year

5.1 During this year a range of topics was discussed by OSAB, predominantly related to use and management of spectrum. We have organised the topics into three broad themes:

- **Planning the long-term use of ultra-high frequency (UHF) spectrum:** ensuring optimal use continues to be made of this important band by a range of services;
- **Technology developments in the core and access networks:** examining recent and emerging developments that will have the potential to improve the delivery of services over both fixed and mobile networks; and
- **The evolution of mobile services:** exploring emerging technologies and options for delivering future mobile services.

5.2 We address each of these topics in turn in the sections below.

5.3 Throughout the year, OSAB also discussed a number of other topics that, for the sake of brevity, are not summarised here. OSAB also was kept informed of progress of activities on which they had provided input in the previous year, such as Ofcom's spectrum management strategy, preparations for the World Radiocommunications Conference (WRC-15) and the Infrastructure Report.

Planning the long-term use of UHF spectrum

5.4 This year, one session was dedicated to topics relating to UHF spectrum, in particular the band between 470 and 790MHz. This band is currently used to deliver digital terrestrial television (DTT) services. However, the physical properties of this band make it attractive for the delivery of a range of services over wide areas and deep into buildings. The top end of this band, therefore, has been identified as a candidate for the future delivery of mobile broadband services.

5.5 Given the potentially competing requirements, the future use of this band has been subject to detailed debate, both here in the UK and internationally. As part of a regular update on Ofcom's work in the area, OSAB discussed three relevant topics. The first approached the topic from a broadcasting perspective, looking at the evolution of services to date, current challenges and likely next steps.

5.6 The next two topics explored how the use of the band might change in the future in order to support both mobile broadband and broadcast services. The three topics and key discussion points are summarised below.

Topic 1: Digital Broadcasting through Freeview, Digital Switchover and next steps

5.7 UHF spectrum generally, and the band between 470 and 790MHz in particular, has been used to delivery broadcast TV services for many years. Transmissions were

initially analogue, but the migration to digital transmission was completed in 2012. The DTT service has continued to evolve and remains the primary delivery mechanism for public service broadcasting content for many.

5.8 An OSAB member gave a presentation on digital broadcasting, which touched upon the development of the service to date, current challenges and likely next steps. The members noted the following points from the presentation:

5.8.1 That digital broadcasting services are based on the use of digital transmission technologies[1] such as DVB-T &T2 and video and audio compression technologies[2] such as MPEG 2 & 4;

5.8.2 Digital services are carried on a multiplex which can carry many television and radio services in the same frequency channel as one analogue service;

5.8.3 Television broadcast services are transmitted on the very-high frequency or VHF (Band III) and UHF (Bands IV and V) throughout Europe, Africa and the Middle East. The use of these bands is governed by international agreements under the International Telecommunications Union (ITU);

5.8.4 The ITU runs Regional Radiocommunications Conferences (RRC) which make specific allocations of spectrum within a designated band to allow adjacent countries to share access to a common spectrum allocation;

5.8.5 The most recent RRC was held in Geneva in 2006, where it was agreed how the VHF and UHF bands were to be used for digital radio and television broadcasting throughout the region including Europe, Africa and the Middle East (i.e. the area known as ITU Region 1). At this point all of the UHF band Channels 21 to 68 (470 to 854 MHz) were allocated to DTT services;

5.8.6 Switchover from the previous analogue-based TV service to the current DTT service in the UK took place between 2008 and 2012. The DTT provider Freeview is now the UK's number 1 TV provider, delivering content to 10.5 million homes. Furthermore, Freeview HD is the fastest growing HD service in the UK;

5.8.7 DTT is projected to hold around two-fifths of the primary set market for the next 10 years or so (this share is even higher when households' secondary sets are taken into account);

5.8.8 BBC, ITV, Channel 4 and Arqiva have committed to launch a new connected TV service for everyone. The aim is to create a mass market,

[1] The Digital Video Broadcasting (DVB) consortium maintains and develops technical broadcast standards. The DVB-T (the T stands for Terrestrial) and the later DVB-T2 standards are used throughout Europe.

[2] The Motion Picture Experts Group (MPEG) has developed standards for the compression of audio and video content, known as MPEG2 and MPEG4.

horizontal connected TV category which will launch in 2015 under the Freeview brand;

5.8.9 Ofcom is now working with the UK government to develop a long term spectrum strategy, a key aspect of which is the decision whether to clear the 700 MHz band of DTT services in favour of mobile broadband;

5.8.10 Ofcom has prepared a cost benefit analysis (CBA) which looks at all of the costs and benefits associated with the policy choice over the next ten years. Overall the Ofcom CBA proposes costs between £470m - £580m and benefits of £900m - £1.3bn.

5.9 The members discussed the presentation and offered the following comments:

5.9.1 That a longer term timescale of up to 20 years, informing a 5 to 10 year plan, might be more appropriate;

5.9.2 More detail was needed on the cost savings to identify benefits to the consumer as well as to the mobile network operators (MNOs);

5.9.3 Broadcasters would need to provide more HD services as otherwise there would be churn on the platform as viewers migrate to other services;

5.9.4 That a cost effective way of getting the new services out would be to co-ordinate with a new generation of TV sets – such as was the case with 'HD ready' flat screen TVs; and

5.9.5 An internet-connected Freeview service was a possible solution to the number of channels with low audiences. The alternative was to develop the Freesat platform but it would still be necessary to retain DTT in order to keep the options open.

Topic 2: Long-term future UHF spectrum scenarios

5.10 One important factor in deciding how spectrum might be used in the future is the role that technology evolution will play. For example, better technology could allow more data to be transmitted in a smaller amount of spectrum; or it could allow existing services to be deployed in new ways.

5.11 One area of interest is whether emerging technology developments could allow broadcast TV services to be delivered over mobile networks. OSAB received a presentation on a study that explored how these developments might impact scenarios for longer term UHF spectrum use. The members noted the following points from the presentation:

5.11.1 The principal question to be answered from the study was "What are the comparative net benefits to citizen-consumers of delivering services (including fixed and mobile video services) amongst differing UHF spectrum scenarios?";

5.11.2 The study focused particularly on the options for any potential changes to the allocation of spectrum in the range 470-790 MHz to digital terrestrial television (DTT) and mobile broadband (MBB) services;

5.11.3 “Long-term” for the project was taken to be the period starting with the allocation of 700 MHz to mobile broadband, probably between 2018 and 2022 and ending in 2030;

5.11.4 This was a ‘first order’ analysis, that more work was needed to validate the findings and on-going monitoring of changes to demand and technology would be necessary;

5.11.5 The study examined five scenarios, reflecting different levels of use of the band by DTT and MBB services;

5.11.6 The TV services which the DTT platform could deliver under each scenario took into account spectral efficiency improvements through better technology and factored in potential changes to the expected display resolutions of DTT services;

5.11.7 A full UHF release could double MBB spectrum below 1GHz, improving capacity and increasing customer experience disproportionately in hard to reach areas deep indoors or at the edge of coverage;

5.11.8 Network cost savings were evaluated on a present value basis, assuming medium demand growth and technology improvement;

5.11.9 Despite additional spectrum becoming available late in the period (2028) and the existing 700, 800 and 900 MHz availability, cost savings would be significant;

5.11.10 A separate, shared/wholesale network for multicast content could maximise use of the spectrum without sacrificing competition;

5.11.11 MBB networks have been built using smaller cells than DTT despite similar frequencies, due to uplink power limits and downlink unicast capacity needs;

5.11.12 4G technology, known as Long Term Evolution or LTE, deployed at high power on high towers (so-called HPHT sites) could provide similar coverage to DTT with greater flexibility. Combined with eMBMS (enhanced multimedia broadcast multicast services) technology, LTE could be used to deliver broadcast TV services;

5.11.13 Changes to the use of the UK’s existing sites could maintain and enhance existing services, whilst supporting greater flexibility in changes to UHF spectrum;

5.11.14 eMBMS technology is already commercially in use and by 2020 we anticipate the following features will be available:

- Flexibly combine broadcast and unicast delivery on the same LTE carrier;
- Feedback of interference and signal quality in order to optimise configuration, whether broadcast or unicast;
- Able to define multiple overlapping service areas to match broadcast coverage to the area of interest, enabling support for local content delivery; and
- Ability to aggregate carriers across different spectrum bands, including the use of a common supplemental downlink which might be shared between multiple operators.

5.11.15 The downlink-only air interface of DTT is more efficient for wide area coverage to fixed users, but is less flexible;

5.11.16 The analysis suggests that switching off DTT would only make sense with substantial changes to demand; and

5.11.17 The positive attributes of these scenarios can be combined by adjusting the timing of changes based on demand changes and international harmonisation options.

5.12 The members discussed the presentation and offered the following comments:

5.12.1 The study needed to take into account the financial assets of the multiplex operators (such as towers) which were amortized over 20 or 25 year period;

5.12.2 Focus was needed on the benefits, rather than just the costs;

5.12.3 There was concern that a single network to deliver both mobile and broadcast content could stifle innovation. However, some members felt that multiple services could use a common core network and that there would still be places within the network where innovation could take place;

5.12.4 Access must be free at the point of reception otherwise there would be no public service broadcasting. Freesat would continue to increase its market share and provide competition with other platforms;

5.12.5 That the focus should be on infrastructure and not business models;

5.12.6 Infrastructure would need to be shared in order to avoid creating conditions which would deter innovation;

5.12.7 Whilst site locations may be stable, the height of masts weren't due to planning restrictions

5.12.8 In order to understand the patterns emerging from the study, the researchers needed to have reliable data on the numbers of users (particularly with respect to mobile users)

5.12.9 The researchers needed to consider the emergence of 4K and even higher definition video services and the potential for their delivery over DTT infrastructure;

5.12.10 A key issue would be copyright. The network would be capable of distributing the content but what would the business models be for the owners of the content – which would be as important as the network. It was estimated that 80% of mobile data was going to be video and most would be one-way and non-linear (e.g. such as YouTube)

5.13 The Chairman thanked the presenters and said that this was an issue which would receive further consideration by OSAB. OSAB would encourage Ofcom to keep an open mind on how the industry would develop and not exclude possibilities such as free cable or more spectrum becoming available than had been anticipated.

Topic 3: Challenges and opportunities of broadband-broadcast convergence

5.14 OSAB received a presentation summarising the findings of another study (for the European Commission) which looked specifically at the convergence of broadband and broadcast services. The members noted that:

5.14.1 The purpose of the study was to assess the likely future developments in audio-visual consumption in the next 15 years across the European Union. It also explores the merits of moving to a converged platform that uses UHF spectrum over a common infrastructure for both terrestrial broadcast and mobile services;

5.14.2 The converged platform is required to provide both a DTT network and additional mobile services with the same geographical coverage of the DTT network as now and with adequate choice of TV channels for end users. Two case studies are considered, depending on the platform capacity - 60 Mbps capacity (Case 1) and 180 Mbps capacity (Case 2);

5.14.3 There would need to be a release of sufficient UHF spectrum to justify the costs of transition and there would need to be a viable transition process;

5.14.4 There were two possible options to consider:

- Option 1 - move DTT network from high power high tower (HPHT) to low power low tower (LPLT) using LTE transmission; and
- Option 2 – as per Option 1 but with DVB transmission.

5.14.5 The transition process to get to either option is complex. For example, for Option 1 we need to change the current LTE specification, run the HPHT and LPLT DTT networks in parallel, convert TV sets for LTE broadcast and reorient perhaps 20% of TV aerials to point to the new transmitters;

5.14.6 Programme making and special events (PMSE) users also operate in this spectrum and would need to be moved to accommodate any changes to the band. Audio devices would be the main issue, with demand for spectrum estimated to be over 100MHz and with the potential to grow further;

5.14.7 The likely cost of replacing current PMSE audio equipment for a country of 20 million people was €30m or several hundred million Euros for moving to a converged platform;

5.14.8 The tentative conclusions of the study were that the incremental benefits from moving to a converged platform were highly uncertain. Evidence to date indicates that benefits from mobile TV would be small and there is no evidence of substantial benefits from integration of broadband and interactive services on a mobile device;

5.14.9 The incremental costs of a converged platform were more certain, and arise from building the LPLT broadcast network, ensuring end-users can use it and clearing the simulcast spectrum and mitigating interference effects;

5.14.10 The incremental costs are lowest if and when impacts of over-the-top or internet-delivered content are strongest, if the converged platform only supports primary DTT sets and in member states with low current DTT penetration;

5.14.11 In these circumstances net benefits might be generated through moving to a converged platform. However, in the same circumstances moving to free-to-view satellite would generate greater net benefits; and

5.14.12 The case for a converged platform would be very difficult to make if the TV broadcast load is increased from 70 to 180 Mbps.

5.15 The members discussed the presentation and offered the following comments:

5.15.1 OSAB wondered if the study had started at the right place as broadband could supplement part of the service if properly directed to where it is needed;

5.15.2 That TV services were being delivered by 3G in the UK (and in Japan, where there was substantial use of mobile TV, the service was free) where there was localised demand not unicast demand;

5.15.3 There was the issue of the EU exercising greater control over member states which would be resisted at the member level;

5.15.4 The study should focus only on mobile data. Most connected TVs have a WiFi chip and would use WiFi in a non-linear way because it is cheap. There would be little economic sense in also building into TV sets an LTE receiver for UHF transmissions;

5.15.5 OSAB noted that the study was based on a country of 20m people and thought that the recommendations might be impractical for a country of a higher population (such as the UK with 60m people);

5.15.6 OSAB noted that there was a very slow movement away from delivery of broadband to a fixed location and that it will still dominant the market for some time. The only immediate benefit was that of spectrum release. In five years' time the situation may be very different;

5.15.7 That there would be a convergence between radio and TV industries;

5.15.8 Terrestrial broadcasting will still be the most efficient way of delivering services – particularly where a 'live experience' is being delivered;

5.15.9 5G would have a different set of demands and its development could be impeded if a new network was designed;

5.15.10 Was there any evidence of any generational shifts in the demand for DTT – i.e. households who have not 'cut the cord' and households where there is no cable connection; and

5.15.11 That demand for content went in 10 year cycles – viewing was lowest amongst 16-24 year olds and the pattern changed for 24-30 year olds. It should be remembered that 20 years ago there was no choice.

Technology developments in the core and access networks

5.16 The evolution of technology can benefit networks and the services delivered over them in a number of ways. The most commonly cited effect of improved technology is speed, i.e. the next generation of network technology will deliver faster data rates to consumers. However, other aspects of network performance can also benefit from improved technology.

5.17 During the year, OSAB received two presentations on how technology developments could impact core and access networks. One updated the board on an emerging technology to deliver ultrafast broadband to premises, while the other explored how improvements in computational power was changing how network resources are managed.

Topic 1: G.fast technology update

5.18 OSAB received an update on the technology, known as G.fast, for delivering ultrafast broadband connections. The members noted that:

5.18.1 The most widely deployed next generation access (NGA) technology in the UK today is fibre to the cabinet (FTTC) combined with very high bit rate digital subscriber line (VDSL) between the cabinet and the premises;

5.18.2 Typical user speed 15 to 70Mbps (up to 100Mbps with VDSL vectoring);

5.18.3 FTTC and VDSL is not considered as future proof as cable or fibre to the home (FTTH). Fibre to the Distribution Point (FTTdp) will take fibre even closer to the customer to exploit G.fast technology, at a lower installation cost than FTTH. The typical user speed will be 200 to 500Mbps;

5.18.4 There is a higher cost, with combined capex and install costs around three times greater than FTTC as each distribution point has ~10 lines (UK average). Operating/maintenance costs are also higher than FTTH;

5.18.5 Netflix is already offering an ultra HD (or 4k) streaming service in some markets and the number of 4k films in production has ramped up. TV manufacturers have forsaken 3D TVs to focus on 4k support;

5.18.6 A 4k movie is approximately 28GB in size, more than 4 times of HD movie. Network bandwidth requirements for 4k streaming are typically 20-30 Mbit/s;

5.18.7 5G and even emerging 4G technologies are expected to involve small cell deployment, which in turn could benefit from the lower latency and higher speeds of G.fast;

5.18.8 The International Telecommunications Union (ITU) completed the G.fast standard last year. The Broadband Forum is developing use-cases, network and management architectures and future interoperability "plugfests";

5.18.9 The first version of G.fast will use a bandwidth of 106MHz, with 212 MHz being planned for the future (possibly 2017), substantially increasing throughput. By comparison, VDSL2 runs on a max of 17 or 30MHz bandwidth depending on the copper spectrum plan;

5.18.10 Standard-compliant chipsets are expected late 2015 or early 2016. Several pre-standard tests and trials completed and deployment is expected from 2016;

5.18.11 For G.fast, voice can be delivered as VoIP via the FTTdp broadband connection. The copper from the distribution point back to the cabinet and then exchange is then redundant for a customer with FTTdp;

5.18.12 However, there will be non-G.Fast customers in the same cable so the copper cable cannot be removed. This has implications for how common maintenance costs are apportioned;

5.18.13 Issues to consider include coexistence between DSL and G.fast services, the evolution towards widespread use of VoIP for telephony services and implications for consumers' reverse powering network equipment at the distribution point.

5.19 The members discussed the presentation and offered the following comments:

5.19.1 That there was still the need for a final line connection and that would impact on broadband speeds;

5.19.2 That the switch off of copper services (when it came) would need to consider the allocation of costs. Whilst fibre could act as an incentive to remove copper it would be balanced against the need to connect all homes;

5.19.3 Connection via a small cell or macro cell would have implications for the network infrastructure and spectrum usage. Ofcom should monitor the uptake of G.fast to identify opportunities for reducing spectrum usage;

5.19.4 There could be an impact on accessing emergency services. The ability to make a call to the emergency services relied on a copper connection to the centralised network or back-up batteries being in place;

5.19.5 If voice over WiFi was adopted it would have extremely important legacy implications; in particular that there was no incentive for BT to go to a non-copper network;

5.19.6 The solution to replacement of copper was to ensure that there were incentives for the market to develop solutions; and

5.19.7 That small cell deployment could form the basis for a good, low cost, cellular network.

Topic 2: Network Functions Virtualisation

5.20 The continued increase in computational power, known as Moore's Law, is leading to a change in the way that communications networks are managed. OSAB received a presentation on the related topic of Network Functions Virtualisation (NFV). The members noted the following points from the presentation:

5.20.1 The classical network appliance approach was characterised by fragmented non-commodity hardware and physical installation per appliance per site. Hardware development was a large barrier to entry for new vendors, potentially constraining innovation and competition;

5.20.2 The NFV approach allowed a competitive and innovative ecosystem for software vendors, automatic and remote installation and high-volume, off-the-shelf servers, storage and switches;

5.20.3 Layering in NFV would allow appliances to become 'network apps'. This replaces the "box business" by "software licence business", opens the market for innovation and facilitates easier operational handling. In addition, software runs on a virtual machine (VM) and therefore is moveable;

5.20.4 There are several motivations for the move to NFV:

- Lower costs: The network will utilise cheaper, general purpose standard hardware;
- Faster time to market: standard hardware deployed faster, just software deployment once cloud infrastructure is in place;
- Better performance: The Cloud enablers processing elasticity (network can automatically adapt to customer/traffic demand)
- Greater resilience: automatic provisioning reduces manual configuration error.

5.20.5 However, not all NFV functionality will reside in a 'central Cloud'. Some services benefit from being close to the end-user e.g. one WiFi hop away. This will give rise to 'Cloudlets' – the computer equivalent to local caches;

5.20.6 Virtualisation applied to Fixed Access:

- Residential Gateway functions moved to Cloud = cost, simplicity, innovation;
- Business Router functions moved to Cloud = innovation, customer 'stickiness';
- Broadband Network Gateway moved to Cloud = cost, scale and improved fixed-mobile convergence; and
- 'Virtual Network Operators' supported = shared network infrastructure costs.

5.20.7 Virtualised Customer Premises Equipment (vCPE) involves simplifying the CPE, reducing costs and operational overhead, extending the CPE lifecycle, enabling faster service innovation, greater visibility of residential home devices and easier IPv6 migrations;

5.20.8 Virtualisation of the access network allows a Virtual Network Operator (VNO) to operate, control and manage its own virtual networks, saving deployment cost of network infrastructure. For the Infrastructure Provider, it allows the ownership and maintenance of physical network resource and enables physical resource virtualisation;

5.20.9 Implications for Ofcom to consider include the increased latency through centralisation of certain functions to 'the Cloud' – will services degrade? Also, what are the resilience implications of centralisation and the impact of dynamic workloads on network performance;

5.20.10 Other implications include whether the UK has the skills required to embrace the opportunities from NFV and the need to assess the potential impact on market structure.

5.21 The members discussed the presentation and offered the following comments:

5.21.1 That the implications for consumers, as well as the enterprise, need to be considered;

5.21.2 That the centralisation of services in the cloud might have the effect of reducing the scope for competition. Members felt that the opportunities for innovation would be at the edges of the network;

5.21.3 That the proliferation of gateway devices and functions could lead to a material increase in costs to the consumer, although there would need to be a uniformity of devices and common operating systems;

5.21.4 Different manufacturers would have different standards and over time this could lead to a loss of efficiency. The ability to make changes quickly would need to be ensured;

5.21.5 There would be data protection issues to be addressed, depending upon where the data is stored;

5.21.6 There would be an issue of network reliability. The network could become too complex for anyone to understand leading to a greater reliance on machinery. This could be an issue for network providers as they tend to be very conservative in their approach;

5.21.7 In addition to the physical issues of operation, software issues would also have to be recognised and addressed.

The evolution of mobile services

5.22 The past year has seen continued deployment of high speed 4G mobile services and equipment manufacturers, network operators and policy makers have begun to look ahead to the next generation. This year, OSAB discussed a number of topics related to the development of mobile networks and their related technologies, of which three are summarised here.

5.23 The first examined emerging and potentially disruptive technologies that could have an impact on spectrum management policies. The other two offered complementary views on the future prospects for mobile network operators, given recent technical and commercial developments.

Topic 1: Disruptive mobile technologies

1. OSAB received a presentation on the issue of disruptive mobile technologies and their potential impact on spectrum policy. The members noted the following points from the presentation:

5.23.1 That scenarios had been created for the rate of mobile technology evolution in the form of spectral efficiency gains. While the scenarios appeared

smooth in aggregate, in practice they consisted of specific steps (or occasional leaps);

5.23.2 The transition between 2G and 3G is characterised by a 25 times increase in channel bandwidth, the introduction of turbo coding and basis multiple input multiple output (MIMO) antenna systems;

5.23.3 The transition between 3G and 4G is characterised by the introduction of orthogonal frequency division multiple access (OFDMA), more complex MIMO systems, wide channel bandwidths, carrier aggregation and a flat, all-IP architecture;

5.23.4 A significant amount of research is ongoing to develop next generation 5G systems. For the past 10 years, it seemed that there had been few significant technology evolutions, with the biggest change being the adoption of smaller cells;

5.23.5 However, some new technologies are now emerging that could have significant impacts on spectrum policy. They include:

- Advanced waveforms to support the diverse requirements of mobile broadband and M2M;
- Co-ordinated scheduling for super-dense base stations;
- Tie-domain beamforming with very large numbers of antennas;
- New radio interface concepts and so-called massive MIMO (in the 15 GHz Band)
- Super-wideband hybrid beamforming and beam tracking (in the 28 GHz Band)
- Super-wideband single carrier transmission and beamforming (in the 70 GHz Band)

5.23.6 The development of the latter three of these technologies is focused on frequency bands above 10GHz, which is an emerging trend for 5G;

5.23.7 Full duplex is another emerging technology. It enables the transmission and reception of data at full bandwidths at the same time and in the same channel. The concept is physically sound, could double spectrum efficiency and would eliminate the need to allocate spectrum for time division or frequency division systems. Applications include contention-free Wi-Fi and small cell backhaul in the same spectrum as the access network;

5.23.8 Massive MIMO shapes and co-ordinates the beams of many, co-located transmitters in such a way that the user gets their very own, localised “bubble of capacity”. A dramatic increase in capacity is possible, although practical implementation would not be trivial;

5.23.9 Spin Angular Modulation involves the transmission of multiple signals on the same frequency by changing the orbital angular momentum. This technique is already used in wide guided optics. There is some scepticism about the practicality of this technology, with claims of infinite capacity appearing to break the second law of thermodynamics;

5.23.10 Impacts on spectrum policy include the potential end of allocating paired and unpaired bands, the potential need for less spectrum if technology evolves faster than demand and the breaking of the current separation between licensed and unlicensed technologies;

5.24 The members discussed the presentation and offered the following comments:

5.24.1 That new technologies could make it necessary to develop a new regulatory model for 5G. Ofcom had a duty to ensure that there were no impediments placed on the auction process which could limit applications;

5.24.2 The spectrum management functions of Ofcom itself could become obsolete;

5.24.3 There was a need to think about the co-existence of neighbouring countries to ensure that all development was in the same direction; and

5.24.4 There would be no distinction between fixed and wireless operators.

Topic 2: Mobile communications – a bright future for operators

5.25 This first of two presentations on the future prospects for mobile network operators focuses on opportunities. The members noted the following points:

5.25.1 There is an ever increasing capacity demand, driven by increasing smartphone penetration and usage. Average monthly usage was 390MB in 2014/15, a 39% increase from the previous year. 4G usage was 16% in Europe and doubling year on year in India. 75% of data traffic was video and browsing in Europe as at September 2013;

5.25.2 With every generation of mobile network the sceptics have been proven wrong. In 1991, downlink and uplink speeds were 9.6kbps. In 2014, the downlink speed was >75Mbps and uplink >30Mbps.

5.25.3 Increasing number of ‘things’ were on the move – and radio was at the core;

5.25.4 Future applications could be serve by mobile networks, and will require very low latency. For example, augmented reality and driverless cars;

5.25.5 Convergence is happening at all levels and will be facilitated by a future architecture built on software defined networking and network functions virtualisation.

5.26 The members discussed the presentation and offered the following comments:

5.26.1 New business models would need to develop which could track lots of services. Agility was essential as otherwise operators would not be able to respond to what consumers wanted;

5.26.2 How will competition change with the advent of new services? It was possible that the number of network operators would reduce;

5.26.3 There would be a shift from a vertical to a horizontal market with different layers of service and access. There was a grey area where the lines of openness should be;

5.26.4 It would be a software defined network with all services being integrated. Some services, in order to be effective, would be vertically integrated;

5.26.5 Operators would need to adapt to change. Large European telecommunication operators were too big to have the necessary agility. There would be a need for a serious transformation and many service providers could collapse;

5.26.6 The current network was not maximised for efficiency. There was a need for a new approach to optimise flexibility in order to cope with the growth in more and more applications; and

5.26.7 OSAB thought that MNOs would be reluctant to change their business model as this would impact on their monopoly position. Operators were not noted for being philanthropic.

Topic 3: The dark future of (traditional) mobile operators

5.27 This second of two presentations on the future prospects for mobile network operators focuses on emerging challenges. The members noted the following points:

5.27.1 New kinds of partnerships and power relationships are increasingly emerging, for example:

- Wi-Fi First – devices which use Wi-Fi as the primary network and cellular networks to fill in the gaps. Offers tremendous benefit to consumers and opening doors for entirely new business models;

- Scratch Wireless – cellular fallback remains an option but customers are encouraged to stick entirely to Wi-Fi – a vastly different model than those MVNOs that are counting on social sharing or ad viewing in exchange for minutes;

- Cable Wi-Fi Alliance – have deployed hundreds of thousands of hotspots and are turning millions of home routers in 'neighbourhood hotspots' by issuing a second, 'public' SSID;

- GoogleFi – network of networks to improve coverage WiFI or T-Mobile or Sprint – what is best and with a simplified payment structure;

- Devicescape – keeps end users best connected by integrating cellular connectivity with public, private and carrier WiFi to create a seamless, quality-controlled mobile data experience.

5.27.2 There are so many new technologies which cannot be ignored that will form the building blocks of a new way of doing things. They include *cloudification*, software defined networking, cognitive radio and dynamic spectrum access;

5.27.3 The skies are back in play, with service providers such as Project Loon, Facebook and KickSat looking to deploy broadband services from airborne platforms;

5.27.4 Core technologies that, on the one hand are part of what the MNOs are interested in, are also the doorway to completely new ways of doing things;

5.27.5 Different forces and coalitions are emerging and Born-on-the-Internet Players are thinking outside the box. Even if the MNO, as we know it, is one of the players in the game, there would be significant power shifts. The concept of an operator needs to be redefined;

5.27.6 Ideas around competition and where the point competition arises need to be considered – wholesale infrastructure (via coalitions) and new kinds of virtual operators;

5.27.7 Ideas of roaming, nationally and otherwise are being challenged.

5.28 The members discussed the presentation and offered the following comments:

5.28.1 Effective competition would depend upon the attitude of regulators to innovation. Entrenched operators could find themselves in a position of advantage;

5.28.2 The market must adapt quickly to change;

5.28.3 New technology companies are either short-lived or absorbed by established companies;

5.28.4 The network may change but ownership will not. Existing operators should be able to adapt more quickly than new entrants;

5.28.5 Virtualization of the environment at the service level was at the leading edge of the changing market;

5.28.6 Ofcom should focus on the universal service aspects of the changes to ensure that public policy objectives are met. That universal service should be built into the physical infrastructure of the network;

5.28.7 That Ofcom's role was limited by statute. It was up to the government to ensure that the regulator had the tools to continue to focus on the benefits to consumers in a situation where the market was adapting to continual change;

5.28.8 That a new approach was needed to convergence to reflect the changes that had taken place since 2003. How will investment work in the changing market and how will the regulator ensure that it takes place;

5.28.9 Markets were changing (e.g. Internet of Things). Who will pay for public integrated services? How will the new markets be monetized and how will they be regulated?

Annex 1

Ofcom Spectrum Advisory Board – Terms of Reference

A1.1 The Ofcom Spectrum Advisory Board is to provide independent, strategic advice to Ofcom, and where appropriate to Ministers, on matters that directly or indirectly have a bearing on policy issues to do with future communications architectures, access methods, physical layer technologies, spectrum, services and applications.

A1.2 In formulating its advice, OSAB is to consider the future communications landscape from technological, economic and societal perspectives, consonant with Ofcom's statutory duty to further the interests of citizens in relation to communications matters.

A1.3 In particular, OSAB is to advise on:

- Ofcom's spectrum strategy, major UK national allocation decisions, spectrum management, and the application of spectrum pricing/trading.
- Issues that are currently "beyond Ofcom's headlights" to which Ofcom should start to give attention.
- New communication technologies.
- New means of managing the radio spectrum and their implications for Ofcom.
- Whether Ofcom's current and developing policy stance is appropriate and where new policy might be needed.

A1.4 For example, topics that might be considered by the OSAB include:

- The extent to which future wireless and fixed communications infrastructure and services may be complementary or compete with one another.
- Novel technologies such as cognitive radio
- Ongoing initiatives such as digital TV switchover.
- Emerging uses of spectrum in areas such as transport and healthcare.
- Ways to measure and assess the effectiveness of spectrum management policies.
- The development of market-led initiatives such as SURs.
- The balance between licensed and licence-exempt spectrum.
- The stimulation of innovation through spectrum policy.

- Trends in international relations.

- Ways that spectrum policy could be used to further the interests of the citizen and consumer.

A1.5 To avoid any conflict of interest, members of OSAB will not have access to confidential information pertaining to Ofcom decisions affecting specific companies. This does not however preclude the discussion of potential Ofcom policies.

A1.6 With the support of Ofcom staff, reporting shall include an Annual Report, publication of key findings on the Ofcom or OSAB website and hosting occasional Open Forums.

A1.7 Members of OSAB should be drawn from a mix of commercial, academic and consulting backgrounds, in order to assess topics in a multidisciplinary manner, and to advise Ofcom on matters of strategic significance. Membership will include ex-officio representation by the Department of Culture, Media and Sport (DCMS) who will participate fully in discussions but reserve the right to abstain from agreement on substantive matters. Members will not receive remuneration other than reimbursement of expenses.

Annex 2

Membership of OSAB[3]

David Meyer (Chairman) [May 2018]

David Meyer served in the British Army's Royal Corps of Signals from 1979-2010, leaving as Brigadier and Deputy CIO. During his career he held positions delivering operational information systems and services; leading units responsible for policy, procurement, operations, signals intelligence and computer network defence; and serving overseas in Croatia, Bosnia, Kosovo, the Democratic Republic of Congo, Iraq and Afghanistan. David joined the Foreign and Commonwealth Office as Chief Information Officer in December 2010. He holds a Master's degree in International Studies and is a Fellow of the British Computer Society and a Chartered IT Professional.

Greg Bensberg [May 2017]

Gregory Bensberg is currently the General Manager of Digital UK Ltd, the UK's main commercial public service DTT multiplex carrying ITV and Channel 4 services to over 98% of UK households. He is a leading authority on both the technical and regulatory aspects of digital broadcasting and has over 30 years' experience as a regulator and digital broadcast engineer.

He has previously worked as a policy and technical expert for Ofcom, the UK government and the Independent Television Commission for over 20 years. He acted as a key technical and regulatory adviser to a number of Government Ministers between 2002 and 2003 whilst they were developing the UK government's switchover policy. He was also responsible for leading Ofcom's spectrum clearance programme (800 MHz and 2.6GHz) which enabled the UK's 4G spectrum auction in 2013.

He developed and led the planning and licensing of the UK's digital switchover programme (including its UHF spectrum strategy) and its adoption of the DVB-T2 standard and the launch of terrestrial HD services in 2009. He also led Ofcom's Digital Dividend Review project in 2005/06, which laid out the process and principles for the eventual European digital dividend programme.

Gregory is a chartered engineer and holds an MBA and BSc. He joined the ITC in 1992 after spells working for Marconi, the IBA, Quantel and Thames Television.

He was awarded an MBE in 2014 for services to communications and media.

[3] After each member is given the date that their appointments to OSAB expire.

Professor Linda Doyle [May 2018]

Linda Doyle is the Director of CONNECT and Professor of Engineering and the Arts in Trinity College, University of Dublin. CONNECT is a national research centre focused on future networks and communications and is co-funded by SFI and industry. CONNECT is headquartered in Trinity College and is spread over ten different academic institutions in Ireland. Prof Doyle is also the Director of CTVR – the research centre that was the precursor to CONNECT. Her expertise is in the fields of wireless communications, cognitive radio, reconfigurable networks, spectrum management and creative arts practices. She has raised over 70 million in research funding in the past decade and has published widely in her field. Prof. Doyle has a reputation as an advocate for change in spectrum management practices and has played a role in spectrum policy at the national and international level. Currently she is a member of the National Broadband Steering Committee in Ireland, and is a member of the Ofcom Spectrum Advisory Board in the UK. Prof. Doyle is on the advisory board of Wireless@KTH in Sweden. She is a Fellow of Trinity College Dublin. She is on the Board of the Festival of Curiosity -- a STEM outreach activity for children based on a city-centre yearly science festival. She is a judge in the BT Young Scientist, Ireland's premier science competition for school children. She is on the Boards of the Douglas Hyde Gallery and Pallas Studios. Prof. Doyle is a Director of Xcelerit and SRS, two CTVR/CONNECT spin-outs.

Robin Foster [March 2015]

Robin Foster has occupied several board-level strategy and policy positions in the UK media and telecommunications sectors and is currently an independent adviser on regulatory, policy and strategic issues. He is a founding member of Communications Chambers, a media and communications consultancy.

Robin was part of the first senior team at the then newly-established regulator, Ofcom, as Partner, Strategy and Market Developments, where he led the first Ofcom review of public service broadcasting. His previous senior positions include director of strategy and regulation at the Independent Television Commission, director of strategy at the BBC, and director of economic consultants NERA, where he was responsible for a range of projects on privatisation, regulation and spectrum management.

Since leaving Ofcom, Robin has advised government in two roles: as a member of the UK Digital Britain Steering Board, which developed proposals for UK broadband communications sector policy and regulation and as one of the independent advisers to the UK Convergence Think Tank. He also ran the Global Communications Consortium research programme at London Business School until March 2008, and was Research Fellow at Bournemouth Media School from 2000 to 2002 where he led a programme of research into the future of media regulation in the UK ("Future Reflections").

David Harrison [ex-officio]

David is Director of Technology Strategy in Ofcom. He is responsible for leading Ofcom's technical research programme and supporting Ofcom policy development across a wide range of areas including: white space and cognitive radio, unlicensed Wi-Fi spectrum, radio switchover, network neutrality and next generation broadband access. David led the UHF Strategy project, which sought to identify the how to best balance the competing demands

for UHF spectrum by different services including terrestrial broadcasting and mobile broadband. He has also led work on new approaches to spectrum sharing to increase the future supply of spectrum for mobile broadband and machine to machine applications. More recently he has been working on the technical criteria needed to provide reliable mobile coverage.

Before joining Ofcom, David worked for the Independent Television Commission where he held the position of Deputy Director of Technology, and before that led the high frequency research and development activities in Thomson Multimedia based in Rennes.

David has published numerous technical papers on RF and high frequency engineering and holds 12 patents. David has a first class honours degree and PhD in Electrical and Electronic engineering. He can be contacted at david.mark.harrison@ofcom.org.uk.

David Hendon [ex-officio]

David Hendon is a senior advisor at Ofcom, working on spectrum, international strategy and network resilience issues. He is a member of the Smart Meters Strategic Reference Group and the Smart Meters Steering Group at the Department of Energy & Climate Change and a non-executive director of Multiple Access Communications Ltd and ContinuumBridge Ltd. He is independent Chairman of the 4G/TV Co-existence Oversight Board established by DCMS. He is a Visiting Professor and, Chairman of the Strategy Advisory Board of the 5G Innovation Centre at Surrey University, deputy-chairman of the Radio Communications Foundation and a member of the IET's Communications Sector Panel.

From 2002 to 2011, David was a Director in the Department for Business, Innovation & Skills where he was responsible for BIS's business-facing activities and policy in communications networks, internet, software and computer services, information and cyber security, electronics, digital content, media, publishing and postal sectors and, from 2010, the Office for Life Sciences. .He was previously Chief Executive of the Radiocommunications Agency, which managed UK radio spectrum prior to the establishment of Ofcom. His earlier career included appointments in the Ministry of Defence, the Home Office, Cabinet Office and the Department of Trade & Industry, all involving electronic communications. He was Chairman of the Board of the European Telecommunications Standards Institute from 1996 to 1999 and a council member of the Engineering and Physical Sciences Research Council from 2006 to 2009. He is a CBE and a Fellow of the Royal Academy of Engineering.

Phillipa Marks [May 2016]

Phillipa Marks is a Director of Plum Consulting. She is an international expert in economic, regulatory and policy analysis of spectrum management issues and has advised operators, regulators and governments in Europe, Asia-Pacific, Middle East and North America on a wide range of spectrum management issues. She also advises on public policy and regulatory issues in the media and telecommunications industries. She was educated in New Zealand and at Oxford University. After a period as a research officer with the New Zealand Institute of Economic Research, she moved to the UK working for the Institute of Transport Studies. She then joined the National Economic Research Associates (NERA) where she became a director, leading assignments in media, telecommunications and utility sectors. In 2000, she was appointed by the Home Office as a member of the Gambling Review Body. She is a member of the Irish Electronic Communications Expert Advisory Panel.

Niall Murphy [May 2017]

A technologist, serial entrepreneur and angel investor, Niall co-founded pan European WiFi network The Cloud in 2003, acquired by Niall is founder and CEO of Internet of Things software company EVRYTHNG. A computer scientist by training, Niall has a background in internet infrastructure and software services, and was founder of one of the first Internet service providers in Africa in the mid-1990s, acquired by UUnet in 1998. He contributed as a policy adviser on telecoms in South Africa in the early 90s through an African National Congress (ANC) think tank. He has co-authored patents and standards submissions, including a the WiFi roaming framework adopted by the IETF.

Robert Pepper [May 2017]

Robert Pepper leads Cisco's Global Technology Policy team in areas such as broadband, IP enabled services, wireless, security, privacy and ICT development. He joined Cisco in 2005 from the FCC where he served as Chief of the Office of Plans and Policy and Chief of Policy Development beginning in 1989 where he focused on telecommunications regulation, spectrum policy, and policies promoting the development of the Internet. Before joining government, he held faculty appointments at the Universities of Pennsylvania, Iowa and Indiana, and was a research affiliate at Harvard University. He serves on the board of directors of the U.S. Telecommunications Training Institute (USTTI), advisory boards for Columbia University and Michigan State University, and is a Communications Program Fellow at the Aspen Institute. He is a member of the U.S. Department of Commerce's Spectrum Management Advisory Committee and the U.S. Department of State's Advisory Committee on International Communications and Information Policy. Pepper received his BA. and Ph.D. from the University of Wisconsin-Madison.

Jean-Jacques Sahel [May 2016]

Jean-Jacques is currently Vice-President, Europe (Global Stakeholder Engagement), at ICANN. Jean-Jacques is a strong advocate for the open Internet and multi-stakeholder model of Internet governance, in Europe and beyond. For over 15 years in both the private and government sectors, Jean-Jacques has been involved in international government and regulatory affairs. Before joining ICANN in 2014, Jean-Jacques headed government and regulatory affairs for Skype, then digital policy at Microsoft for Europe, Middle-East & Africa regions.

Jean-Jacques was the UK signatory of the 2006 UN ITU Convention and Constitution and has chaired the UK Chapter of the International Institute of Communications since 2009.

Simon Towler [ex-officio – February 2015]

Simon Towler is Head of Telecommunications Policy in the Department of Culture Media and Sport, with responsibility for telecoms regulation, spectrum and broadband policy. Simon joined the Department of Trade and Industry in 1992. He has held policy posts in civil aerospace, international trade policy, nuclear issues, telecommunications policy

and better regulation as well as a secondment to the British Embassy in Washington DC. Simon joined the DCMS in January 2011 together with other colleagues responsible for telecommunications policy and relations with the sector. He was appointed to his current post in June 2011.

Mike Walker [May 2016]

Mike is a telecommunications consultant. Until his retirement in September 2009, Mike was the Group Research and Development Director for the Vodafone Group of companies, with the responsibility for the Group's research activities, intellectual property and technology standards worldwide. He is a Vodafone Fellow and an Executive Technical Advisor to Vodafone. He is a member of the Board of the European Telecommunications Standards Institute, having been chairman for the 2008-2011 Board period. Mike is a non-executive director of Avanti and is a Trustee of the Alacrity Foundation. He holds the Vodafone Chair in Telecommunications at Royal Holloway, University of London. He is a Fellow of the Wireless World Research Forum. Mike is a Fellow of the Royal Academy of Engineering, and until June 2011 served as a member of Council of the Academy. He was the President of the Institute of Mathematics and its Applications for the Presidential term 2010-2011. He was awarded an Honorary Doctorate of Technology from the University of Plymouth in 2011. He was appointed an OBE in June 2009 for his services to the telecommunications industry.

Gavin Young [May 2018]

Gavin's current role is as Head of the Fixed Access Centre of Excellence within Vodafone. He is responsible within Vodafone Group for the fixed broadband access strategy, architecture and deployment practises across the 17 countries where Vodafone currently has fixed access assets.

Gavin was previously Head of Strategy & Planning in Cable and Wireless Worldwide leading a team of architects responsible for the technology architecture and strategy. He had previously worked at Bulldog Communications (later acquired by C&W Worldwide) where he held a variety of responsibilities from product development through to the network operations and CTO. Prior to that Gavin led the Access Architecture & Design team at BT.

Gavin was a founding director of the Broadband Forum where he was overall Technical Chairman for twelve years. In addition he has been co-chair of the UK21CN consultation's Broadband Group, chair of the UK NICC's DSL Task Group and also vice-chair of the NICC Ethernet Access Task Group. Gavin also serves on the IET Communications Policy Panel and the Ofcom Spectrum Advisory Board (OSAB).