Future of the UHF band after 2034

An analysis of options in the UK

FINAL REPORT

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1. Executive summary

The UHF (Ultra High Frequency) spectrum is a critical resource that supports three key sectors in the UK: Digital Terrestrial Television (DTT), Mobile Communications, and Programme Making and Special Events (PMSE). Each of these industries provides significant socio-economic benefits and has strong claims to access UHF spectrum. However, with limited available bandwidth, no future scenario can fully satisfy all stakeholders. This report assesses the impact of potential spectrum reallocation and outlines strategic policy recommendations to optimise spectrum use while minimising adverse effects.

DTT remains a vital platform, with 49.6% of UK households relying on it for primary or secondary television access as of 2024[1] and the percentage of DTT only households was estimated to be 11.6% representing some 3.3 million homes in 2023[2]. While audience preferences are gradually shifting towards online content consumption, DTT continues to serve vulnerable populations who may lack access to alternative platforms. A significant reduction of the DTT service would primarily impose social rather than economic costs, particularly on lower-income and elderly demographics due to digital exclusion. According to the House of Lords' Digital Exclusion 2023 report, an estimated 2.4 million adults in the UK do not possess the essential digital skills required to carry out basic online tasks, such as connecting to a Wi-Fi network[3].

Mobile communications, which is growing and represents circa 0.75% of the UK's total Gross Value Added[4] [5] [6], on the other hand, faces increasing demand for low band spectrum to enhance rural and deep indoor coverage and capacity. Mobile broadband can provide an alternative where fixed broadband is unavailable, especially for lower-income households. Without additional sub-1 GHz allocations operators will have poorer indoor coverage and network congestion in rural areas is expected to worsen, exacerbating rural digital exclusion and hindering economic growth. Without additional sub-1 GHz spectrum, operators may also face challenges densifying their networks and delivering more reliable, lower latency services which offer customers a better quality of service.

PMSE supports the UK's growing creative industries, which contribute over 5% or £124 billion in Gross Value Added (GVA)[7]. It relies on UHF spectrum for high-quality audio transmission, essential for live performances, broadcasting, and content production. Unlike mobile and DTT, PMSE's spectrum demand is highly localised and predictable, making efficient spectrum-sharing mechanisms a viable solution.

Given the finite nature of UHF spectrum resources, trade-offs are inevitable. Interviews with stakeholders identified various socio-economic risks associated with spectrum insufficiency, though not all impacts carry the same weight. For instance:

- Limited mobile broadband access in urban areas with widespread fixed broadband is less concerning than a lack of rural mobile coverage due to spectrum congestion. For example, a broadband link with Wi-Fi can be used as a substitute for a mobile network in case there is poor indoor coverage.
- Reduced quality of service in mobile networks is a lesser issue compared to a loss of connectivity for PMSE.
- A decrease in DTT channel offerings is preferable to the total loss of television access for vulnerable groups.
- A full DTT switch-off could encourage those without broadband to get online, particularly if accompanied by digital skills training and an awareness and adoption campaign plus the availability of social tariffs.

Balancing these needs requires careful consideration of economic, social, and technical factors although note this report focuses primarily on the technical spectrum issues.

[1] Ofcom Communications Market Interactive 2024

[2] Ofcom, Future of TV Distribution, May 2024

[3] House of Lords, Digital Exclusion (2023)

[4] UK Government DCMS and DSIT, Digital Sector Economic Estimates Value Added 2022 (provisional), November 2024

[5] Ofcom, Communications Market Report 2024

[6] Imperial College, The UK Telecommunications Sector 2024

[7] Creative Industries: Growth, jobs and productivity, January 2025, House of Lords Library

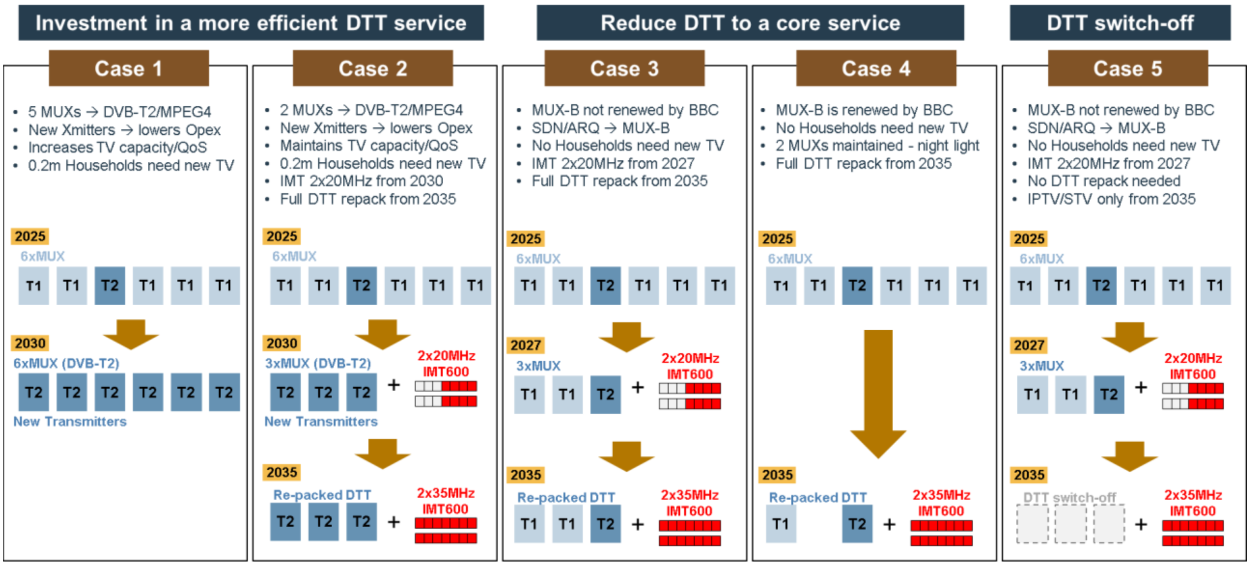
https://lordslibrary.parliament.uk/creative-industries-growth-jobs-and-productivity/

DTT in the UK could evolve in many ways over the next decade, and the evolution and choices will be influenced by a myriad of factors. Ofcom's Future of TV Distribution[8] concluded that there were three different broad approaches could be taken. After conducting an extensive literature search as well as holding interviews with 17 stakeholder organisations and considering the above trends, we have identified five main cases as follows:

- Case 1 falls under the Ofcom approach for investing in the DTT network for a more efficient service. Case 1 is the case where six Multiplexes are maintained and the current five using DVB-T with MPEG2 video coding are upgraded to DVB-T2 with AVC/MPEG4 video coding. This case boosts TV Channel capacity (quantity of channels) and/or quality of service (e.g. HD channels) significantly within the same DTT frequency allocations. A key motivation for this case is to also take advantage of the latest generation of much more energy efficient DVB-T2 transmitters thereby reducing operating costs, so a more sustainable network can be achieved in business terms. PMSE continues as at present, using interleaved broadcast spectrum. No IMT600 spectrum is carved out and this reflects a case where mobile operators in the UK and in Europe may also not need extra low band spectrum either because demand for spectrum is lower than anticipated or there is delayed support for the band. Case 1 is not considered particularly likely and is included for reference.
- Case 2 also falls under Ofcom's approach for investing in a more efficient DTT service, where TV channel capacity and quality mix is maintained using three Multiplexes all using DVB-T2 with AVC/MPEG4 video encoding. In this case, energy costs can be reduced further. Case 2 also provides an opportunity to release some IMT600 spectrum whilst maintaining existing agreed DTT UHF channel allotments and hence does not require any major re-engineering or spectrum coordination efforts. Case 2 however assumes that by 2035 a full UHF channel re-pack can be delivered releasing a full 2 x 35 MHz IMT600 band plan, aligned with a European consensus for IMT600. In both cases 1 and 2, there is also a need to invest in upgrading some households which have DVB-T only receivers by 2030. It is estimated that there would be only 0.2m DVB-T households with primary TV sets by 2030 and we believe that this could be achieved much earlier than 2035. Without carefully considered mitigation solutions, PMSE would be adversely affected.
- Case 3 falls under the Ofcom approach for reducing DTT to a core service. In this case, there is no investment made into the DTT network or in upgrading TV sets. Case 3 also assumes that the BBC decides not to renew its MUX-B Multiplex licence and hence reflects a market driven decline in DTT supply. In this case, the Commercial Multiplex operators can consolidate from three DVB-T/MPEG2 Multiplexes onto the single vacated MUX-B Multiplex and take advantage of the enhanced coverage. There are no domestic TV upgrades needed for case 3. A partial IMT600 dividend is possible as early as 2027, followed by a full DTT channel repack delivered from 2035 with a 2x35 MHz IMT600 band plan. Without carefully considered mitigation solutions, PMSE would be adversely affected. A partial IMT600 allocation may allow mitigation measures to be tested.
- Case 4 also falls under Ofcom's approach for reducing DTT to a core service, but here we assume a more straightforward transition from six Multiplexes to two Multiplexes from 2035. As such, this case does not require changes to Multiplex licences. A full DTT channel repack is delivered from 2035 as clearance for IMT600 services. Even though there are fewer Multiplexes than previous cases, without carefully considered mitigation measures, PMSE would still be adversely affected.
- Case 5 follows the same trajectory as case 3 but plans for complete DTT switch-off from 2035. In case 5, it is assumed that IPTV becomes the dominant TV distribution method replacing DTT altogether. From 2035 there is no need for any DTT re-pack and IMT600 can be made available as soon as DTT sunsets. Despite no broadcast Multiplexes, PMSE could still be affected, and mitigation measures would still be required. In considering the substitution of DTT with IPTV and the associated absorption of traffic into broadband networks, it will be essential to address factors such as service quality, reliability, and the effective management of peak demand live events. In addition, there is a question about the future use of frequencies below 614 MHz in this case.

[8] https://www.ofcom.org.uk/tv-radio-and-on-demand/public-service-broadcasting/future-of-tv-distribution/

Exhibit 1: Overview of DTT evolution cases assessed



Source: Coleago Consulting

Based on our discussions with stakeholders, case 1 is not considered very likely and is included for reference only. Cases 2 to 5 (or variants thereof) are all seen as potential outcomes post 2035 with cases 3 to 5 seen as potentially more likely. A lot will depend on the attitude of the broadcasters in the coming years towards DTT and their willingness to fund its continued use and any potential upgrades. One decision point will come at the end of 2026, when the BBC must decide whether to renew its MUX-B licence which carries HD channels. If the largest Public Sector Broadcaster (PSB) in the UK takes a step back from DTT it may encourage other broadcasters to review their plans and ultimately hasten a move towards IPTV (case 5).

In our DTT cases, we propose that the current Multiplexes could be changed in the interests of all parties. For example, as per case 2 if the BBC decides not to renew its MUX-B licence then Arqiva and/or SDN may find use of this DVB-T2/MPEG4 Multiplex layer for improved coverage. We recognise that the BBC Charter, multiplex pricing policy and potential changes to legislation may be affected or influence these issues and a full cost benefit analysis needs to be done before proceeding. Note this study addresses only the technical spectrum issues, and these other points are outside the scope of this study and will have to be addressed by Ofcom and the government in due course.

In cases 2, 3, and 4, where there is a reduction in the number of Multiplexes, the decrease in DTT spectrum may offer the opportunity, as an interim step, for an early national 2 x 20 MHz allocation within an IMT600 band plan. Such a partial 600 MHz allocation could be supported within the existing DTT spectrum user rights and channel allotments, minimising the need to adjust existing bilateral agreements between the UK and neighbouring countries including France, Ireland, Belgium and the Netherlands. An early release of IMT spectrum without the need for a full DTT frequency re-plan including international coordination may provide a testbed before committing to release of the wider band.

Also in cases 2, 3, and 4, a re-packing of the DTT network is assumed for beyond 2035 to release a full 2 x 35 MHz IMT600 band plan which would require international coordination. This would imply that neighbouring countries such as Ireland and France also wish to allocate 600 MHz for mobile services. We estimate the costs of re-packing the DTT network for 600 MHz clearance should be substantially lower than for the 700 MHz clearance. This is largely due to our assumption that main DTT sites would require far less antenna re-engineering or swap-outs, since wideband antennas were already deployed during the 700 MHz clearance. Also, a halving of Multiplexes from 6 to 3 may lend itself to leveraging the two RF combining groups used at most DTT sites in a way to minimise the need for deployment of temporary masts and antenna systems. This would need to be confirmed and costed by stakeholders such as Arqiva.

For this study we have not engaged in a formal cost benefit analysis of spectrum value where more detailed costs are required. Such a cost benefit analysis may form part of future studies led by DCMS, DSIT or Ofcom and be informed by studies such as this report. We have not included any analysis of the numerous economic or financial cases for commercial broadcasters paying for DTT capacity as our remit was to focus on the more technical spectrum issues. Similarly, considerations regarding potential cost efficiencies from consolidating services onto a single platform, such as IPTV, were excluded from the scope. Please note several key players from the broadcasting sector did not participate so we had limited information on the DTT network cost elements.

Although any formal cost benefit analysis of the different cases was outside the scope of this project, we did attempt to quantify some aspects:

- The allocation of the IMT600 spectrum via an auction could raise a significant amount for the exchequer and potentially improve consumer welfare. Based on Ofcom's 2021 auction price of £280 million for 2 x 10 MHz of 700 MHz spectrum, the auction of 2 x 35 MHz of 600 MHz spectrum could potentially raise an estimated £980 million, assuming comparable market conditions and spectrum value (which is of course subject to uncertainty). Please note that these were the prices paid and may not fully represent the value that the operators placed on the spectrum, nor indeed the consumer welfare derived from its use, which is likely to be much higher still[9]. From a consumer welfare perspective, Deloitte and the Digital Poverty Alliance estimate that addressing digital poverty could generate billions in annual benefits for individuals, government, and businesses. Their research suggests that enhancing digital connectivity access could lead to an estimated £17 billion in additional earnings for individuals[10]. Even a small contribution from IMT600 would be highly valuable: each 1% of the £17 billion estimated by Deloitte would add £170m in social value.
- The DTT upgrade costs and the potential energy savings that may come from the use of more modern DTT technologies. To do this we had to resort to high-level public domain sources as not all key stakeholders were available to provide the required information. One of the key insights is that the latest generation DTT transmitters offer significant increases in power efficiency and may be even more efficient by the 2030s. For example, if we consider case 2, an investment in DTT allows only three DVB-T2/MPEG4 Multiplexes to provide the same TV channel capacity as today's six Multiplex DTT network with a significant reduction in energy costs. Over the next 10 years, these savings alone could justify the necessary investment into the DTT network plus the upgrading of household TV receivers to support DVB-T2. During this study we were not able to establish detailed costs of capital equipment such as new DVB-T2 transmitters and their required power ratings for the 80 main DTT broadcast sites, nor establish current DTT operational and energy costs. Estimates for such costs would have been best gleaned from Arqiva for this study. However, Arqiva did not participate in this study. As such, we used public domain material and our own assumptions to arrive at high-level estimates for costs associated with each of the five future UHF evolution cases.

To minimise societal harm and optimise UHF spectrum use, this report recommends a balanced policy approach:

- Spectrum Sharing – Dynamic allocation mechanisms between mobile and PMSE, particularly in rural areas, could enhance network capacity while preserving essential PMSE services.
- Targeted Infrastructure Investments – Expanding fixed broadband affordability[11] and availability can reduce dependency on mobile networks mitigating coverage and congestion issues. For example, if there is no mobile coverage then fixed broadband with Wi-Fi can provide a substitute.
- DTT Modernisation and Public Support – If DTT is to be maintained (per cases 1 to 4) then investments in technological advancements and potential public funding mechanisms will need to be explored.
- International Coordination – The UK's spectrum policy should align with global standards to maintain economies of scale in equipment manufacturing and cross-border interoperability.

In all cases except case 1, without mitigation measures there would be a reduction in available UHF spectrum for PMSE. Our analysis suggests that this reduction would currently impact up to 50 high-demand PMSE applications such as festivals, theatres, studios and sports events and potentially more in the future with the expected growth in high-demand PMSE applications[12]. Mitigations may include further increases in the re-use of spectrum in time and location at large events; the introduction of new technologies such as WMAS which promise substantial spectral efficiency gains for large events; the further use of the Aeronautical band, and the idea of exploring leasing some of the currently unused 25 MHz within the 700 MHz duplex gap. We also propose the idea of geographic and time-sharing coordination between IMT and PMSE industries with robust spectrum polices and protections for PMSE which would enhance the value of PMSE because more frequencies would become available at the limited number of high-demand locations and times.

[9] Telefonica, It's all about value not price: Europe versus the US, July 2022

[10] Deloitte and the Digital Poverty Alliance, Digital Poverty in the UK: A socio-economic assessment of the implications of digital poverty in the UK, December 2023

[11] Ofcom, Communications Affordability Tracker: Around a quarter of UK households (23%) had difficulty affording communications services in January 2025

[12] See Section 4

The future of the UHF band requires a pragmatic and strategic approach that recognises the competing needs of DTT, mobile, and PMSE. While spectrum limitations present challenges, innovative policy solutions - such as targeted sharing mechanisms and infrastructure investments - can help maximise benefits while mitigating socio-economic disruptions. This report aims to contribute to the ongoing discourse and support evidence-based decision-making to ensure an equitable and sustainable spectrum allocation strategy for the UK.

2. Introduction

2.1 Background

The allocation and use of the Ultra High Frequency (UHF) band have been a subject of extensive regulatory and technological discussions, particularly as we approach the expiration of the UK's Digital Terrestrial Television (DTT) broadcast licenses in 2034. The decisions made regarding the UHF band (470–694 MHz) will significantly impact multiple stakeholders, including broadcasters, mobile network operators, and users of Programme Making and Special Events (PMSE) equipment. This report examines the future of the UHF band in the UK, evaluating potential scenarios and regulatory considerations for its post-2034 usage.

The regulatory landscape for UHF spectrum has evolved in recent years. At the World Radiocommunication Conference 2023 (WRC-23), mobile services were granted a secondary allocation within the UHF band in 44 European countries, excluding Italy and Spain. In parallel, the 614–694 MHz range has been designated for co-primary International Mobile Telecommunications (IMT) use in AMSG (Arab Spectrum Management Group) nations. The next major opportunity to review the allocation of this spectrum will be at WRC-31. In the UK, Ofcom has been tasked with monitoring user trends and proposing strategic options for the UHF band beyond 2034, ensuring that the nation gains the maximum benefit from the use of this spectrum.

In 2022, UKSPF commissioned Coleago to study the usage, market, and technology developments, as well as potential changes in viewing and consumer habits. Our previous report[13] proposed four potential scenarios for the future allocation of 470-694 MHz frequencies. Considering Ofcom's report and its three proposed approaches to managing the band, it is timely for us to update the findings of that study.

2.2 The changing media landscape and spectrum needs

The television and media landscape continues to experience significant changes, primarily driven by the rise of broadband internet access and the proliferation of streaming platforms. Linear television viewing has declined, with an increasing portion of audiences - especially younger demographics - migrating to online services. However, DTT remains an essential service for millions of UK households, particularly those with older, less affluent, or disabled individuals who rely on free-to-air television. In response to these changing dynamics, Ofcom has outlined three potential approaches to managing the future of DTT and the broader UHF band:

- **Investment in a more efficient DTT service:** This scenario envisions maintaining a robust DTT service while optimizing efficiency through improved transmission standards and equipment upgrades.
- **Reducing DTT to a core service:** A minimised DTT platform retaining only essential public service and news channels, with most content accessed via broadband.
- **Move towards DTT switch-off in the longer term:** A long-term plan to phase out DTT entirely, ensuring universal internet access for television services.

Each approach presents unique technical, economic, and social implications that are carefully assessed in this study.

2.3 Balancing stakeholder interests

The future allocation of the UHF band must consider the diverse and sometimes competing interests of various stakeholders:

- Broadcasters and DTT Viewers: Maintaining a viable broadcast service is crucial for public service broadcasting and media plurality. Any reduction in spectrum must ensure continued accessibility for underserved populations.
- Mobile Network Operators (MNOs): The mobile industry advocates for reallocation of UHF spectrum to improve network capacity, particularly for 5G and future 6G deployment in rural and indoor environments.
- Programme Making and Special Events: PMSE users depend on UHF spectrum for wireless microphones and other production tools, particularly for live events and broadcasting.

13 See 'Future Utilisation of the 470-694 MHz Band in the UK', Coleago Consulting, November 2022.

This report analyses the trade-offs between these sectors, focusing on spectrum efficiency gains, potential migration costs, and the broader societal impact of reallocating UHF frequencies.

2.4 Key socio-economic considerations

DTT, Mobile, and PMSE each deliver significant socio-economic benefits to the UK and have strong claims to UHF spectrum.

DTT

Despite a shift among all but the very oldest category of audiences from linear to non-linear content viewing, as of 2024, 49.6% of households still relied on DTT - either as their primary TV access method or for additional sets within the home. While this report does not explore scenarios where DTT ceases to exist, such an outcome would likely leave vulnerable social groups without access to television. For the majority, transitioning to alternative platforms would impose predominantly social rather than economic costs, particularly if the overall DTT offering were reduced.

Mobile

Expanding mobile connectivity requires additional low band spectrum to enhance rural and deep indoor coverage. Mobile networks are essential for broadband access, especially where fixed alternatives are unavailable and for lower-income groups who cannot afford fixed broadband. As detailed in Section 5, significant densification of mobile networks (both in urban and rural areas) is not practicable. Without further sub-1 GHz spectrum allocations, deep indoor coverage will deteriorate, and rural congestion will worsen. This would exacerbate the Digital Divide, limit future in-vehicle connectivity, and risk economic harm due to the broader productivity impacts of mobile connectivity.

PMSE

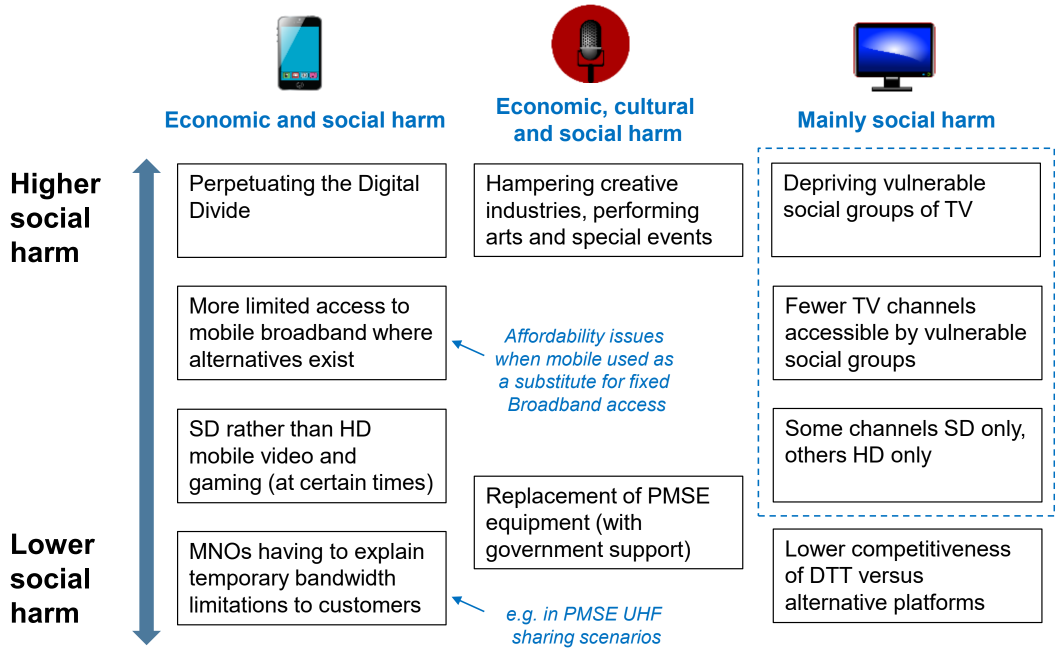
The creative industries contribute over 5% in Gross Value Added (GVA)[14] to the UK economy, PMSE plays a crucial role in this sector, enabling the production of high-value cultural and economic content—much of which is carried by both mobile and DTT platforms. A significant portion of PMSE's spectrum needs is driven by high-quality wireless microphones used in live performances and content creation. While its demand for bandwidth is high and growing, it is typically localised and predictable (see Section 4). Continued access to substantial low band spectrum is essential, as higher-band alternatives above 1.5 GHz suffer from body loss propagation issues, while lower Very High Frequency (VHF) bands can be prone to interference. The UHF spectrum (470-694 MHz) remains optimally suited for professional, body-worn PMSE applications.

Risk of socio-economic impacts

Given the limited resources in this frequency range, no future UHF band allocation can fully meet the needs of all three industry groups. During our interviews, stakeholders identified various potential socio-economic impacts resulting from low band spectrum shortages in their sectors. However, the severity of these impacts varies, making it useful to assess them qualitatively, as outlined below.

[14] Creative Industries: Growth, jobs and productivity, January 2025, House of Lords Library https://lordslibrary.parliament.uk/creative-industries-growth-jobs-and-productivity/

Exhibit 2: Potential outcomes and their relative social harm



Source: Coleago Consulting

Limited access to mobile broadband in areas where fixed broadband is widely available is likely less harmful than a complete lack of adequate broadband due to mobile network congestion in rural regions. In principle, policy measures can help address fixed broadband affordability where infrastructure exists. Likewise, while reduced mobile video quality in congested areas is an inconvenience, it is far less concerning than the total absence of connectivity for rural communities and low-income groups.

A mobile industry respondent highlighted the challenge of maintaining consistent service quality if spectrum resources had to be shared with other users at certain times and locations. However, while managing customer complaints would fall to mobile network operators (MNOs), having additional low band resources in most locations and at most times would still be preferable to not having access at all. Other mobile industry stakeholders share this view. For instance, sharing spectrum between mobile and PMSE could enhance network capacity, particularly in rural areas, helping to bridge the Digital Divide.

In the TV broadcasting sector, a reduction in DTT channel options is less harmful than the complete loss of access to television. Similarly, offering either Standard Definition (SD) or High Definition (HD) programming - rather than both - would impose fewer social costs than significantly reducing the number of available channels. A potential decline in DTT offerings may also make the platform less competitive, potentially threatening its long-term commercial viability. However, public funding could remain an option to sustain its operations. Economic losses within the DTT-specific value chain, while significant, would be less detrimental to society as a whole, provided they do not result in TV access loss for vulnerable groups.

The goal of future policy development should be to minimise harm and net costs to society through a balanced approach. Decisions on UHF spectrum allocation will also be shaped by international developments and the need to maintain economies of scale in equipment and terminal markets. Given that many of the challenges facing the UK are shared by other countries, this may encourage the adoption of common solutions. We hope this report and the scenarios explored within it contribute meaningfully to this ongoing discussion.

2.5 Study objectives and approach

The primary objective of this study is to provide an evidence-based analysis of the potential future uses of the UHF band in the UK, incorporating:

- A detailed assessment of current DTT spectrum efficiency and potential technological enhancements.
- An evaluation of the costs and feasibility of each of Ofcom's proposed scenarios.

- An exploration of the potential benefits and challenges of reassigning UHF spectrum for mobile use, including cost-benefit analyses based on international benchmarks.
- Consideration of the needs of PMSE users and alternative solutions for their spectrum requirements.

The future of the UHF band after 2034 represents a critical juncture for spectrum policy in the UK. This report provides an in-depth analysis of potential pathways, ensuring that the chosen approach supports technological innovation, equitable access to media services, and the efficient use of spectrum resources. The findings will hopefully be instrumental in shaping UK government policy and regulatory frameworks in the years to come.

2.6 Organisation of this report

The remainder of this report is organised as follows. Sections 3 to 6 address key industry issues and trends, for DTT, PMSE, mobile and fixed broadband sectors respectively. Within the context of Ofcom's scenarios, we develop five main cases for future UHF spectrum use, as discussed in Section 7. Section 8 addresses options for optimising the existing IMT low band assignments – these may be relevant irrespective of future UHF outcomes. In Section 9, finally, we suggest areas for further study.

3. Broadcast TV – key trends and issues

The broadcasting landscape currently appears to be in a state of transition and could change significantly over the next 10 years:

- Viewer choice for broadcast TV and content has diversified from the traditional broadcast platforms of DTT, cable and satellite with the emergence of IPTV alongside traditional broadcast TV, i.e. new streaming video on demand services such as Netflix and those of the traditional broadcasters such as ITV-X and BBC iPlayer. Additionally, online social media is also a source of video content, particularly for younger sections of the population.
- Changes in viewer behaviour have seen a major and ongoing shift away from linear broadcast TV to streaming video on demand.
- Changes in receiver technology such as smart TVs, are reinforcing these changes in viewer behaviour. By providing a unified interface for many different types of service, they blur the divide between traditional and newer platforms and also provide additional functionality, such as time shifting TV.
- Innovation in broadcasting technologies, such as more efficient video compression, creates opportunities for broadcasters to deliver better picture quality or more channels for a given spectrum bandwidth, but also creates challenges since new technologies require more network investment (though there are also efficiency savings) and viewers may need new receivers (if not upgraded as part of the natural replacement cycle though set-top boxes and HDMI devices are cheaper alternatives).

These trends have been visible for several years and, in 2022, led the UK SPF to examine the implications for the future use of the UHF Band to develop a policy position for the then upcoming WRC-23.

In the rest of this section, we assess how these trends have progressed since 2022, where they may have accelerated, stalled, and whether any new developments have emerged. In summary, the direction of travel is clearer, though there is still much uncertainty. For example, in December 2022, the Director General of the BBC announced intentions for the BBC to move to digital/online only TV distribution over the following decade, noting the challenges of ensuring no one is left behind[15]. Everyone TV, which leads the evolution of free TV in the UK and is backed by the BBC, TV Channel 4 and Channel 5, launched Freely TV in 2024, a unified streaming service for free TV and bundled with new TV receivers, in order to future proof the delivery of free TV given the increasing popularity of IPTV.

Ofcom's assessment of these trends and the future of TV distribution, in its 2024 report mentioned above led it to the view that DTT may not deliver as well for consumers in the future as in the past and to note concerns over its long-term sustainability[16]. As set out in Section 2 above, Ofcom devised three scenarios for how the broadcasting sector could respond to these changes and preserve the vital societal benefits of broadcasting. We note that universality, the ability of people of all backgrounds to access content which is valuable to them, through which they are connected to others across the UK[17], is particularly important, as is ensuring that no viewers are left behind in any future transition. Furthermore, although the changes to broadcasting may take 10-15 years fully to play out, substantive change will take years to implement if the transition is to be smooth, hence these issues need to be considered now.

3.1 Trends in linear TV viewing share and DTT receiver penetration by technology

The two most significant measures of the changes in linear TV viewing we highlighted in our previous report were a small but significant fall in the reach of linear TV[18], i.e. the proportion of the population regularly accessing programmes or channels, and the minutes of viewing traditional broadcast TV per day, both for the population as a whole and for individual age groups.

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15 https://www.bbc.com/mediacentre/speeches/2022/tim-davie-director-general-royal-television-society

16 Ofcom, Future of TV distribution, 2024, https://www.ofcom.org.uk/tv-radio-and-on-demand/public-service-broadcasting/future-of-tv-distribution/

17 Universality ensures not only that everyone has ready access to a reliable source of news and information, but also to a range of differing opinions and cultural experiences of life in the UK.

18 Defined as 15 consecutive minutes of viewing per week,

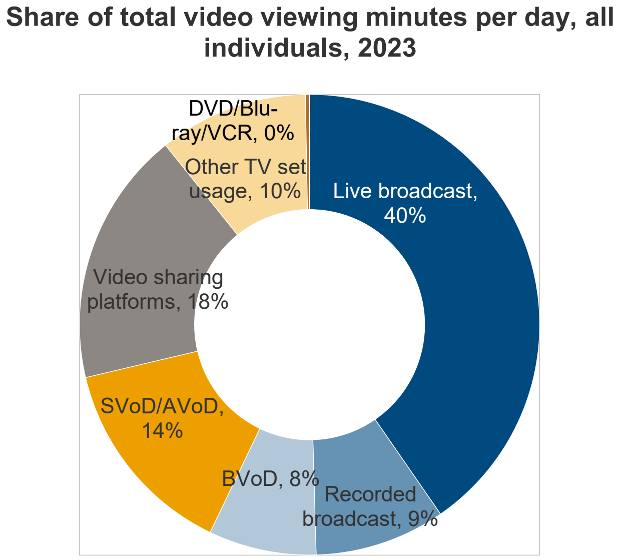
In the 2022 report, we found that the overall reach of linear TV channels[19] (over DTT, cable, satellite, plus via digital video recorder and online catch-up within 28 days of broadcast) was still high at 86.3% in 2021, though it had fallen from 95% in 2011. However, for 16–34-year-olds, reach was notably lower than for the population as a whole at 74.5% (down from 91.4% in 2011).

The decline in linear TV reach appears to have accelerated in the following two years, falling to 75% on average in 2023, for the population as a whole. For 16–24-year-olds, reach was 48% in 2023 and 64% for 25–34-year-olds[20].

In comparison, an Ofcom survey measured the reach of alternatives to the traditional broadcast platforms as follows: iPlayer (74%), Netflix (69%) and YouTube (56%) in 2022[21].

Considering other sources of video content in addition to broadcast TV, we see that the broadcasting sector is now very diverse and, though broadcast TV is still the leading platform, it does not command a majority of video content – its share fell to 40% in 2023 (compared to 45% in 2022).

Exhibit 3: Share of daily viewing of video content, 2023



Source: Ofcom, Communications Market Interactive 2024

In the 2022 report, viewing of linear TV had fallen proportionately further than its reach, from 242 minutes a day in 2011 to 179 minutes in 2021. Again, the fall was steeper for younger viewers going from 165 to 53 minutes a day, for 16-24-year-olds over 2011-2021[22]. This was balanced by a corresponding rise in other video services including streaming video on demand (SVoD) and YouTube giving moderate growth in total minutes watched per day.

These trends have continued, and the subsequent decline has been a little faster for the population as a whole, than for the16-24 years group, which implies that older age groups are ‘catching up’ with younger age groups in their move away from linear TV. Exhibit 4 below extends our previous graph of minutes of linear TV viewing to 2023 and Exhibit 5 presents the same information segmented by age group. It is notable that in every group except the 75+, traditional broadcast TV viewing continued to decline in 2023.

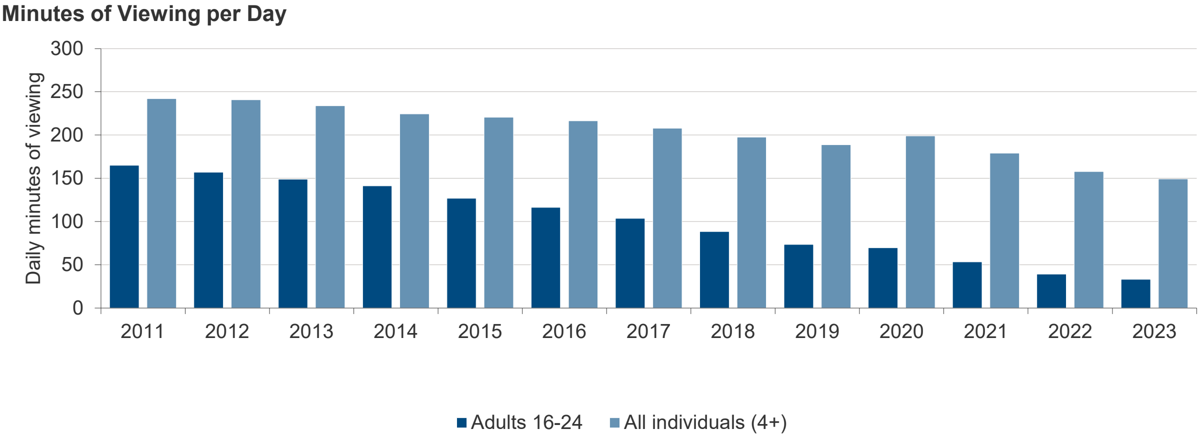
19 Ofcom, Media Nations, 2022, source: BARB

20 Ofcom Media Nations 2024, https://www.ofcom.org.uk/media-use-and-attitudes/media-habits-adults/media-nations-2024/

21 Both reported in Ofcom, Media Nations, 2022, (BARB data, Seven-day consolidated. Reach criteria: 3+ consecutive minutes)

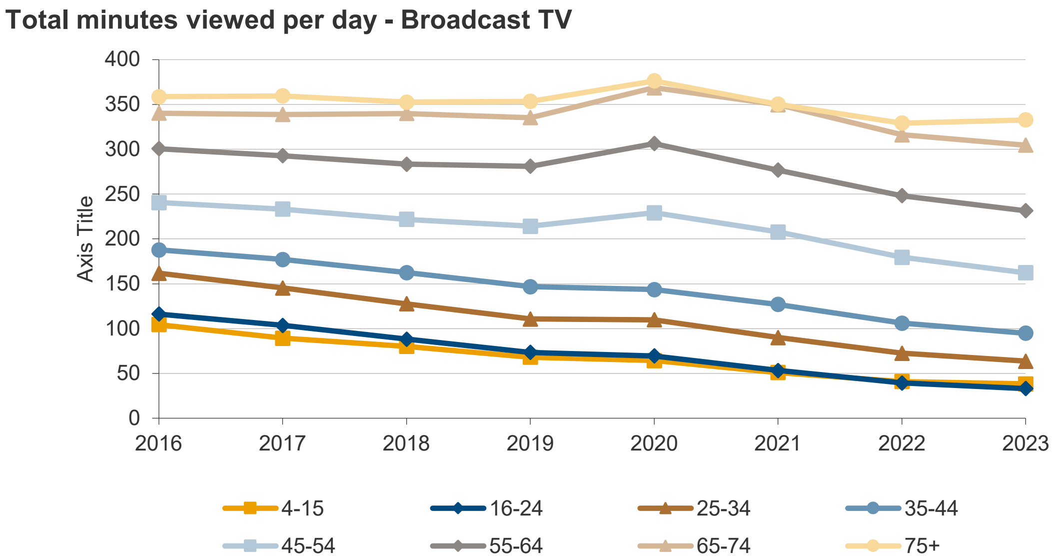
22 BARB, Research criteria is 15+ minutes. As reported in Ofcom Media Nations 2022: Interactive Report, https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/media-nations-reports/media-nations-2022/media-nations-2022-interactive-report

Exhibit 4: Daily viewing of traditional broadcast TV



Source: Ofcom Communications Market Interactive 2024, Barb

Exhibit 5: Minutes of daily viewing traditional broadcast TV by age categories



Source: Ofcom Communications Market Interactive 2024, Barb

In summary, although linear TV is still in a strong position today, the figures confirm a fundamental shift in the consumption of video content in the UK, and this is also happening in our European neighbours. While it is likely that linear TV will remain the largest category of TV consumption in the short to medium term, consumption of broadcasting is now a hybrid for many of online and traditional broadcast content. In the longer term, to 2035, streaming video on-demand and online consumption of video content may come to dominate.

As for commercial broadcasting (PSB and non-PSB), our 2022 report showed increasing competition for advertising revenue from online services, but a post-pandemic bounce back that bucked the previous trend. Since then, revenues are again falling. After the increase to £4.7 billion in 2021[23], broadcast TV advertising revenue fell again to £4.5 million in 2022 and £3.9 million in 2023. In contrast, broadcast video on demand advertising revenues have continued to rise, though from a much smaller base – from £391 million in 2018 to £980 million[24] in 2023. However, it is important to note that high inflation and the associated economic slowdown also affected advertising revenues, and that Ofcom expected 2024 to

[23] Ofcom, Media Nations, 2022

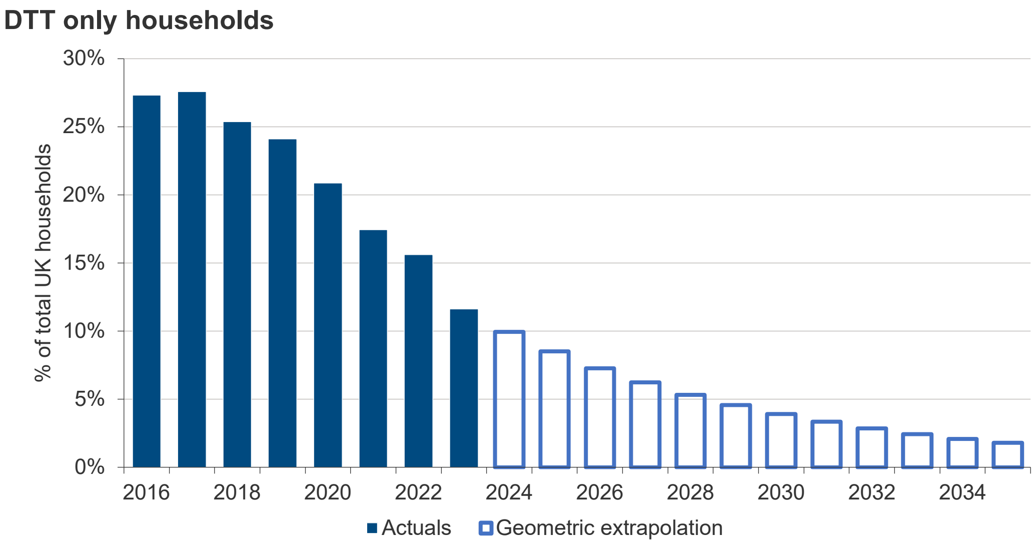
[24] Ofcom, Media Nations, 2024

show a stronger performance[25]. Finally, SVoD companies, which were considering introducing advertising at the last time of writing, have actually done so, though the advertising revenues are currently small: £50 million in 2023[26].

We also noted in 2022, a parallel decline in DTT only households, and a trend towards other platforms such as IPTV and social media, such that the proportion of households where the only receiver is DTT fell by about 40% from 26.8% (7.4m households) in 2016 to 15.4% (4.4m households) in 2022[27]. The number of households with a DTT receiver, including second or third sets however, had fallen less and was still relatively high at 62% in 2020[28].

The number of DTT only households is still falling, and reached 3.3 million[29], 11.6% of households, in 2023, as shown in Exhibit 6 below (the % of households with DTT, including second and third sets, fell to 53% in 2023[30]). Our geometric extrapolation, based on an average of the past 5 years, implies that the number of DTT only households would fall to 1.2 million (4%) in 2030 and 550,000 (2%) by 2035. A less steep reduction, but still a major reduction, was projected by 3 Reasons cited by Ofcom[31]) who estimated the number of unconnected DTT only households at 2 million in 2030.

Exhibit 6: Historic and projected DTT only households



Source: Ofcom, ONS, Coleago

There will be other households where a second or third TV set is DTT (and may or may not be connected to the Internet), several stakeholders recognised that argument for ensuring universal access to television was less relevant to these households.

Our prior, tentative conclusions, that trends in linear TV viewing reach and the growth of alternative content distribution platforms imply that DTT is unlikely to remain dominant and that only a minority of viewers will be dependent on DTT in the longer term, still stand and have been strengthened by the subsequent developments reported above. Moreover, Ofcom has come to similar conclusions in its report on the Future of TV Distribution and some of the major broadcasters have recognised the need to have a prominent IPTV presence as noted above.

However, although DTT sets are increasingly connected - 3 Reasons estimates 80% of primary sets using DTT will be connected by 2027[32] - there may still be a substantial minority not connected. Stakeholders are concerned that this will

[25] Ofcom, Media Nations, 2024

[26] Ofcom, Media Nations, 2024

[27] Ofcom, Media Nations, 2022

[28] BARB, Viewing Report, June 2021

[29] Ofcom, Future of TV Distribution

[30] Barb, Establishment Survey Quarterly Data, Q1 2024

[31] Ofcom, Future of TV Distribution

[32] BBC response to Ofcom Call for Evidence on the Future or TV Distribution, p9

predominately affect, more elderly, disabled and poorer households and emphasise the need to protect these more vulnerable users.

Universal access to appropriate broadband is a pre-requisite for any approach where IPTV becomes a major platform for delivering TV content in the longer term. We examine broadband availability and exclusion in more detail in Section 6.2 below and provide a summary here.

The first conclusion is that availability of broadband is not a substantial barrier to universal access to IPTV, i.e. at a level similar to the 98.5% PSB DTT coverage today. Ofcom estimate that “decent broadband”, at least 10Mbps downlink sufficient to support at least SD quality, has 99% coverage and that only 48,000 households will not be covered by December 2025.

Superfast broadband, of at least 30Mbps and sufficient to support HD, already reaches 98% of premises and gigabit capable broadband, whose rollout is supported by several government initiatives, may cover 99% of premises by 2034 or even earlier.

Instead, broadband exclusion, i.e. households not connected to broadband, appears to be a greater barrier to universal IPTV access than availability. Currently 7% of homes, 1.9 million households, do not have a fixed broadband connection and 4% (1.1 million) rely solely on mobile[33]. Affordability is a concern but was cited by only 20% in Ofcom’s Media Literacy Tracker Survey, whereas lack of interest was cited as a reason by 69%[34].

Hence, although it is a minority of households, a significant number would nonetheless be at risk of considerable social harm - social exclusion, insecurity and loneliness. Their interests would need to be appropriately dealt with a combination of appropriate long-term planning, a possible night-light service, and/or effective assistance (subsidies and for digital skills) in making a transition to online TV access. Though there would be a cost for access to an appropriate broadband service, there may also be associated benefits with increasing digital literacy and reducing digital exclusion in a time when commercial and public services are increasingly available online and may offer advantages over off-line access.

3.2 The impact of new technologies on broadcasting spectrum use

In our previous report for UKSPF, we looked at the impact of new technologies on broadcasting spectrum use and this has been brought into sharper focus now with the first of Ofcom’s three scenarios dealing with a transition to more spectrally efficient broadcast technology.

Greater spectral efficiency in broadcasting use of UHF spectrum could, in principle, be achieved both within the existing DTT network and through a more radical change to a different terrestrial transmission technology. The following trends and barriers to their adoption are explored in this section:

- Upgrading SD channels using MPEG2 Video Coding to H.264/Advanced Video Coding (AVC) with MPEG4
- Switching to DVB-T2 across all multiplexes, with or without HEVC (High Efficiency Video Coding)[35]
- 5G Broadcast
- Single frequency vs. multi frequency networks

However, careful attention must be paid to the cost of any transition (net of savings such as reduced energy costs), the degree to which transition costs are upfront and the financing of the investment required to upgrade networks. Much of the benefits of a more efficient networks would fall to consumers and the beneficiaries of a possible spectrum release, and not necessarily the broadcasters. Moreover, broadcasters would need to weigh up the trade-offs between investing in a platform that is set to decline over the next 10-15 years with investing in online TV delivery to compete with the SVoD and other players in the changing broadcasting ecosystem.

33 Ofcom, Future of TV Distribution

34 Ofcom, Adults’ Media Literacy Tracker surveys 2023

35 By 2030, HEVC H.265 may be superseded by VVC or H.266, though we have not explicitly considered this in our analysis

DVB-T2, is a more spectrally efficient transmission technology for digital transmission than the original DVB-T technology introduced for DTT. DVB-T2 enables higher bit rate transmission and delivers an almost 50% increase in capacity compared to DVB-T[36].

MPEG4, i.e. the H.264/AVC compression standard, would also allow a significant increase in spectral efficiencies where MPEG2 is currently used. Stakeholders generally considered that a potential upgrade to MPEG-4 should be viewed in combination with an upgrade to DVB-T2 – though this should not necessarily be taken as an endorsement of such an upgrade. It should be noted that MPEG4 with DVB-T has been extensively deployed across Europe, and there will be more MPEG4/DVB-T compatible TV sets in the UK versus MPEG4/DVB-T2 compatible TV sets, although this quantity has not been researched or determined.

However, a potential upgrade to H.265/HEVC (High Efficiency Video Coding), which would also offer further gains in capacity in conjunction with DVB-T2, was considered unlikely in our stakeholder interviews. Although some European countries have introduced HEVC, this has been for streaming services. However, for traditional broadcasting content, the cost of licensing for encoders and decoders is a significant barrier to the adoption of HEVC.

In the UK, the use of DVB-T2 is limited - only one of the six multiplexes (MUX-B, sometimes referred to as PSB3) broadcasts on the DVB-T2 standard with the rest using the less spectrally efficient DVB-T. In contrast, DVB-T2 has been introduced in a number of other European countries for example (sometimes alongside HEVC H.265 as in Germany below):

- Belgium (2023)
- France (2016)
- Germany (2017)
- Italy (2021-2023)
- The Netherlands (2019)
- Spain (announced a two-phase plan in 25/03/25 first promoting the adoption of compatible receivers then globally deploying DVB-T2 when receiver adoption is sufficiently high)
- Finland (2017, pay TV, full switchover April 2025)

We note that the broadcast TV landscape in these countries can be significantly different from that in the UK with much higher levels of subscription to cable and satellite services in some countries. This is important because a full transition to DVB-T2 in the UK may involve higher costs given the greater reliance on DTT.

A key factor in the cost of a possible transition to MPEG-4 and DVB-T2 is the number of TV receivers that will still not be compatible at the end of our 10–15-year time horizon. Several interviewees stated that, with a roughly 7-year replacement cycle for TV receivers, by 2035 most should be DVB-T2 and MPEG-4 compatible. This is backed up by estimates published in Ofcom's report on the Future of TV distribution that only 200,000 primary receivers (and 900,000 secondary receivers) are likely to be incompatible with DVB-T2 in 2030 (set-top boxes would offer a lower cost upgrade path).

5G Broadcast is a potential converged mobile and TV broadcasting service which would deliver live broadcast content to mobile devices, including in-vehicle systems. The service would be delivered over 5G using either a broadcast network, a cellular network or an amalgam of the two.

At the time of our last report, 5G Broadcast was still in the early stages of development with a significant number of trials and testbeds having taken place including 5G VISTA in the UK and 5G MEDIA2GO in Germany[37]. However, now 5G Broadcast has been launched in Austria and in a number of countries outside Europe including Brazil, Colombia, Malaysia and Venezuela and trials have taken place in China.

The leading initial drivers of interest in 5G Broadcast are still use cases complementary to traditional broadcast TV such as delivering live content - sports, news, concerts - based on the belief of an unmet demand for live broadcasting since consumers may be on the move when a live event is taking place. Another use case being considered is to use 5G

36 EBU, "Frequency and Network Planning Aspects of DVB-T2", 2011 https://tech.ebu.ch/docs/news/2012_01/wrcdocs/Planning%20aspects%20of%20DVB-T2%20-%20EBU%20TECH3348%20-%20May%202011.pdf

37 For more details of 5G Broadcast trials and projects see: EBU TR 044, "Trials Tests and Projects Relating To 4G/5G Broadcast Supported by European PSB", 2022, https://tech.ebu.ch/docs/techreports/tr044.pdf

Broadcast as a distribution channel for public information during an emergency or natural disaster. By far the majority of stakeholder interviewees viewed 5G Broadcast as complementary, though a few believed that 5G Broadcast could be substitute for broadcast TV in the longer term.

Delivery by cellular network would require compatible handsets. This could be achieved as part of the normal consumer upgrade cycle for handsets, given a sufficiently long transition period and provided appropriate handsets are available, thus reducing the need for specific 5G Broadcast upgrades. Furthermore, apart from the capacity to support the services, delivering 5G Broadcast as another IMT use case would not involve additional network equipment or costs. On the other hand, delivery by broadcast network may require consumers to upgrade their mobile devices. Potentially, the cost of an upgrade could be financed from 5G Broadcast advertising revenues. Moreover, broadcast networks would have to deploy additional Low Power Low Tower (LPLT) sites alongside the current High-Power High Tower (HPHT) network and the additional sites are most likely to be required in urban areas.

If 5G Broadcast did become a replacement for DTT, although the majority view from our interviews that this is unlikely, the traditional receiver (connected to the rooftop aerial) would have to be 5G Broadcast compatible. This would be a major transition that would need to be planned, sufficiently in advance. Questions of affordability, disruption and digital literacy for the minority of users, who may struggle in any transition, would have to be addressed.

Single Frequency Networks (SFNs) have been introduced, at least partly, in a several European countries. In theory, an SFN would use less spectrum for DTT than an MFN and could in principle allow up to 25% spectrum efficiency than a Multi-Frequency Network (MFN)[38], however stakeholders raised a number of drawbacks for deploying SFNs in the UK which in their view would outweigh any advantages.

- The BBC and ITV regions would not be replicable with a national SFN and the benefits of regionality would be lost.
- Extensive and challenging coordination with neighbouring countries would be necessary to carve out a single frequency that could be used across the UK.
- The guard interval required to eliminate self-interference limits the maximum geographic size of the SFN hence coverage will be impacted or with longer guard intervals the payload supported will be reduced.
- Relays may become more difficult to operate in an SFN and off-air reception to feed relays, if needed, is significantly more difficult in an SFN than an MFN, and line feeds may be required instead.
- The need for synchronisation of transmitters, including relays, introduces extra complexity and cost.

In line with these reasons, we found no support in our interviews for deploying SFNs in the UK.

[38] Study on the Use of the sub 700 MHz Band, European Commission, 2021, https://op.europa.eu/en/publication-detail/-/publication/8c6755a1-4f55-11ed-92ed-01aa75ed71a1/language-en

4. PMSE – key trends and issues

4.1 The diversity and high-level economic importance of audio PMSE

Audio PMSE plays an integral role in a range of economic activities that generate substantial economic value added for the UK, as highlighted in our 2022 report. Audio PMSE use in the UHF band comprises a number of different services including radio microphones and in-ear monitors (IEMs) which are used by musicians and television presenters to hear a personalised feed of music or instructions in support of live performance or in content production. These sectors make also contribute significantly to the wider society and culture in the UK, and most appear to be growing after the pandemic despite the economic turbulence in 2022 and 2023. The changes in the key sectors are as follows:

- Spend on film production in the UK continued to grow in 2024, generating £2.1bn, up from £1.97bn in 2022, and having recovered from a dip in 2023 due to the strikes in Hollywood[39]. Notably, Sky Studios Elstree opened in February 2023 and represents a major increase in UK film and high-end TV production capability which could attract further film production to the UK and more spending on high end TV productions especially from SVoD producers such as Netflix, Amazon and Disney+.
- Festivals and concerts revenues increased sharply in 2023 to £6.1 billion, a 17% increase on the year before and a 35% increase since 2019[40].
- Theatre attendance in London had increased 7.2% between 2019 and 2022 with 16.4 million visits generating £900 million in ticket sales[41].

Although PMSE is only part of the inputs used for these events, without PMSE, the attractiveness and value of many cultural, sporting and other events, would be diminished. Furthermore, growth in the underlying creative and sporting sectors should also be reflected in the growth of PMSE use as result.

We reiterate in this report that PMSE users are strikingly diverse and support not only television, theatre and other premium live events but trade fairs, local theatre, religious venues (40,000 churches and 1,825 mosques) and schools (32,000).

4.2 Current use and demand for PMSE spectrum in the UK

Analysis of over 330,000 professional PMSE licences in the 470-702 MHz range was conducted spanning over three 12-month periods. The licence data was provided by Ofcom for this study. We had 12-months' worth of data from our previous study[42] with licence data spanning Oct 2021 to Sept 2022, and we received another two 12-months' worth of data for this study, spanning Jan 2023 to Dec 2024. The data included licence bandwidth, centre frequency, location (resolved to 1km^2 bins), and the duration of licences, resolved down to an hour duration. This data was processed to gain a better understanding of the spatial and temporal demand of PMSE spectrum across the UK.

The exhibit below depicts the number of 1km^2 locations in the UK as a function of effectively occupied PMSE spectrum for the three 12-month periods. These locations include all longer term PMSE licences (>= 30 days licences) for studios, theatres, conference venues, as well as all shorter term PMSE licences (< 30 days licences) for touring performance arts, festivals, sports events and other temporary users. The effective occupied PMSE bandwidth in any location is the sum of all unique spectrum licenses in the 1km^2 area bin. Any narrowband PMSE licences such as 0.2 MHz licenses are considered to effectively occupy approximately 0.5 MHz in bandwidth terms, to recognise the needs of multi-channel PMSE inter-modulation avoidance and management. We arrived at this 0.5 MHz figure based on observations that there was about a 1:2.5 licensed bandwidth to occupancy bandwidth ratio in the data for the locations which used many 0.2 MHz licences, and hence clearly adopting a frequency plan to manage intermodulation interference.

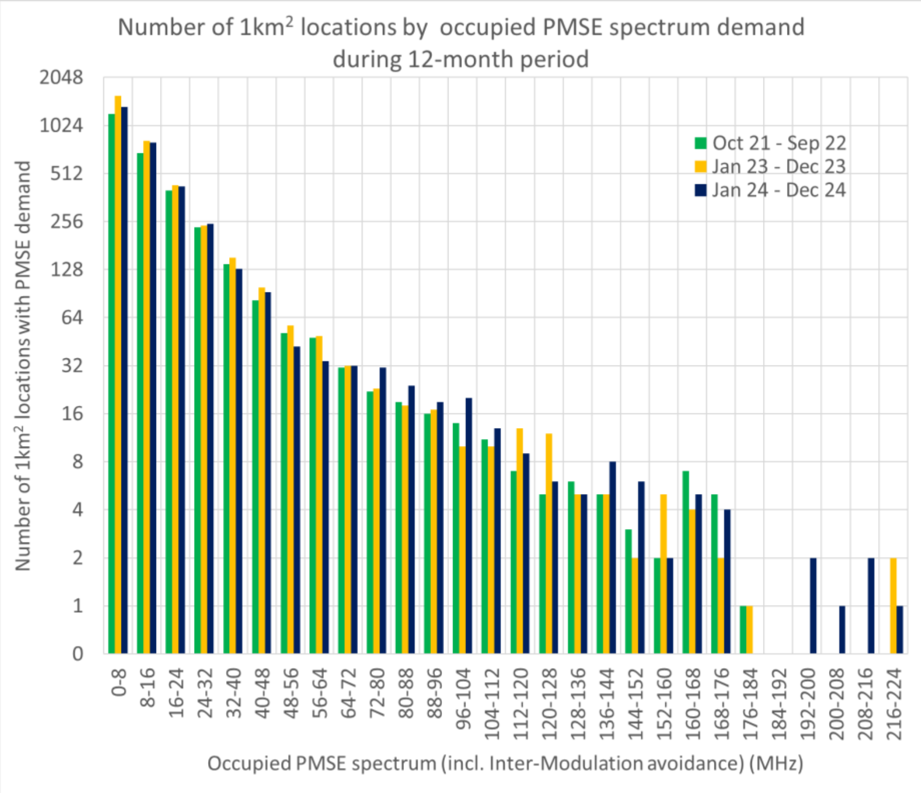
[39] https://www.bfi.org.uk/news/official-bfi-statistics-2024

[40] https://www.artsprofessional.co.uk/news/uk-live-music-sector-revenue-tops-ps6bn-first-time

[41] https://solt.co.uk/box-office-2022-data-london-theatres-ticket-pricing-stays-consistent-despite-rising-costs/

[42] https://www.techuk.org/resource/uk-spf-reports-a-key-insight-into-future-spectrum-policy.html

Exhibit 7: Distribution of unique locations by effective total peak PMSE spectrum occupancy over 12-month period



Source: Ofcom and Coleago

Given the entire full UHF band is 232 MHz from 470 MHz to 702 MHz, DTT effectively occupies 7 x 8 MHz = 56 MHz in most populated locations (from 6x MUXs plus 1x Local TV MUX), and 7 MHz of UHF Channel 38 is offered as a shared PMSE channel (no guarantee of being interference free) means that there is 232 MHz – 56 MHz – 7 MHz = 169 MHz available for PMSE applications which are strictly outdoors as indoor PMSE doesn't need to avoid DTT frequencies, although avoiding DTT is good practice whenever possible to do so. There are however areas in the UK which are served by two main DTT broadcast stations which can mean less outdoor PMSE spectrum is available since another six UHF channels would become unavailable, although there wouldn't likely be a Local TV Multiplex channel being used in the areas served by two DTT main broadcast stations. Examples of such areas include York which is served by both Emley Moor and Bilsdale DTT areas, and areas around Bristol served by the Mendip and Wenvoe DTT transmitters. It is understood that the amount of available PMSE spectrum in a locality can be a key factor in deciding whether a city or wider area is selecting for creative arts opportunities such as TV/film production, or events such as Eurovision.

Where there was demand for greater than 169 MHz for PMSE spectrum within 1km^2, then this will include areas where there was either no Local TV MUX, or no Commercial MUXs, and/or indoor PMSE was certainly used. For example, the two locations in 2023 with 216-224 MHz in the chart above were for the Eurovision Song Contest in Liverpool.

4.3 Future PMSE growth

There is evidence that PMSE spectrum demand in the UHF band has been growing over the three 12-month periods based on our analysis of the PMSE licence data. Overall, there has been about a 11% increase in the number of actual PMSE licences when comparing the 2024 data with 2021/22 data, but with a corresponding increase of around 30% in the total quantity of licenced PMSE spectrum. This growth has been driven by an increasing level of microphone and IEM use across the performing arts, music/art festivals and TV production industry to enhance the quality and sophistication of the entertainment provided to the audience. Recent years have also seen significant increases in the nature, scale, and competition of film and TV productions from Amazon, Netflix and others.

There is also evidence of increases in very high-demand PMSE spectrum (e.g. above 104 MHz) in the data as shown in the chart above, although this is somewhat harder to quantify because the number of very high demand locations remains small compared to all locations and can vary significantly year to year.

In the remaining sections on PMSE trends, we look at whether advances in technology and the likely availability of access to other spectrum bands could alleviate the pressures on the sector caused by the growth trends we have identified, and noting that PMSE has already had to respond to past reductions in the available UHF spectrum due to the release 800 MHz and 700 MHz spectrum for mobile through innovation.

4.4 960-1154 MHz Aeronautical band for PMSE

To address the reduction in available spectrum for PMSE during the 700 MHz spectrum clearance, Ofcom conducted a consultation and technical analysis on sharing the 960–1154 MHz band, traditionally reserved for aeronautical radio navigation services. This band includes systems such as Distance Measuring Equipment (DME) and Secondary Surveillance Radar (SSR), which are used for aviation safety. Ofcom's analysis concluded that low-powered audio PMSE devices could safely share access to this band without causing harmful interference to aeronautical operations. Consequently, Ofcom permits PMSE users to operate within specific sub-bands of the 960–1154 MHz range.

The band is specific to the UK at present which can mean vendor equipment can be more limited. Over areas such as London it has been calculated by one stakeholder that the band can provide something like 56 MHz of PMSE spectrum, but PMSE lost about 77 MHz during the 700 MHz clearance. However, the band is starting to see some growth in usage and offers a promising meaningful quantum of PMSE spectrum to compensate for the loss of 700 MHz spectrum for PMSE use. Last year's Glastonbury event saw this band being used at scale with a major act on the main Pyramid stage[43].

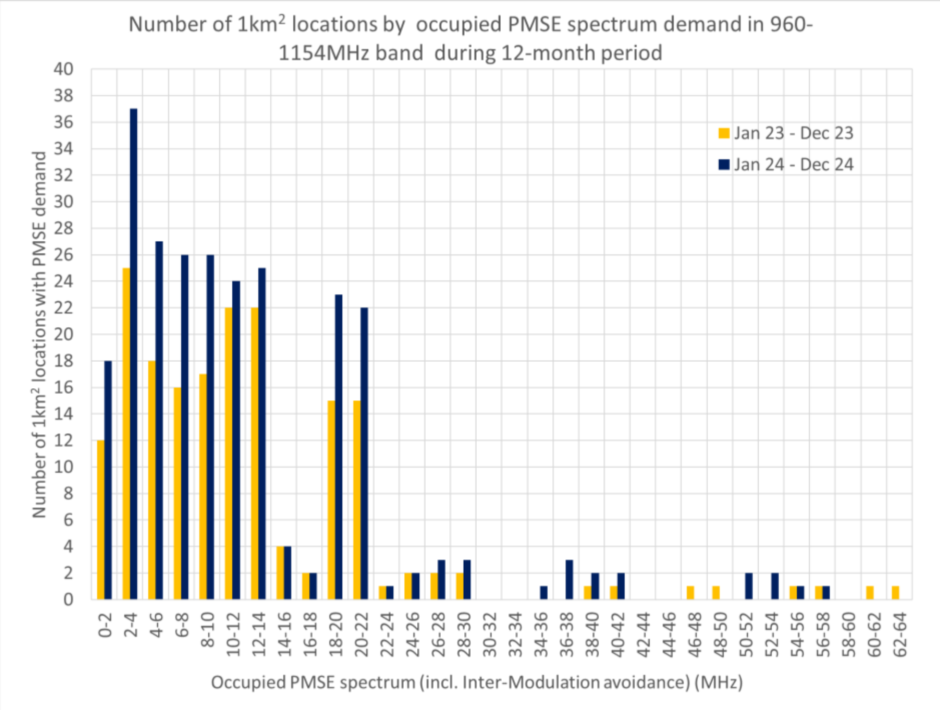
One concern raised by stakeholders was the potential change in the Aeronautical band with new Aeronautical band services being introduced in the coming years, and whether this may erode PMSE spectrum availability. New Aeronautical band services such as L-Band Digital Aeronautical Communications System (LDACS) is planned for introduction from 2030, and additional Military Aeronautical communications links such as Link-16 may remove 3 MHz of the band from PMSE. A very recent change announced by Ofcom to this PMSE band is 3 MHz in the range 976.5 MHz to 979.5 MHz is now unavailable for PMSE[44] and related to spectrum allocated for Universal Access Transceiver (UAT) for additional aeronautical safety equipment. However, Ofcom has also announced four 1 MHz blocks of spectrum in this band has become available which wasn't available before 11 March 2025.

Ofcom provided PMSE licence data for 2023 and 2024 for this 960-1154 MHz band for this study. The chart below illustrates the demand for PMSE spectrum expressed as the number of 1km^2 locations by total PMSE spectrum and presented using a linear vertical axis (unlike that shown for the corresponding chart for UHF PMSE licence demand which showed a Logarithmic scale). Our calculations for PMSE demand include a multiplication factor to account for Inter-Modulation interference avoidance and management. PMSE spectrum demand up to around 20 MHz is clearly seen with only a relatively small number of locations with greater than 22 MHz PMSE spectrum. This apparent breakpoint in the distribution may be a function of what spectrum is available from the DME band under coordination rules, although we did not investigate this aspect.

[43] https://www.ofcom.org.uk/spectrum/radio-equipment/ofcom-at-glastonbury-2024/

[44] https://www.ofcom.org.uk/spectrum/radio-equipment/pmse/

Exhibit 8: Distribution of unique locations by effective total peak DME band PMSE spectrum over 12-month period



Source: Ofcom and Coleago

Most of the DME PMSE demand was highly correlated with UHF PMSE demand in both time and locations which is to be expected. However, there were many areas where there was high UHF PMSE demand, yet no DME PMSE demand which may suggest that PMSE was met by UHF but also indicates that some PMSE demand relief would be possible in the future in the event there was less UHF spectrum available for PMSE.

4.5 Recent technological advances - WMAS

Significant improvements in audio PMSE spectrum efficiency have been made in recent years. For example, as a result of the introduction of digital technology, equipment is now able to deliver around 2.5[45] to 3 times the number of audio channels in a fixed amount of radio spectrum whilst achieving acceptable levels of quality (though analogue PMSE does still retain some performance advantages over digital). In addition, the development of very linear power amplifiers has increased spectral efficiency of PMSE equipment by improving its intermodulation performance.

However, one emerging and promising technology for the PMSE industry is Wireless Multichannel Audio Systems (WMAS). This technology is being introduced by vendors such as Shure and Sennheiser and is designed to use a shared wideband radio channel (such as an 8 MHz UHF channel) to maximise capacity and optimise management of multiple wireless links such as radio mics, IEM's, talkback radios which may have different Quality of Service (QoS) requirements associated with a theatre production, TV studio, or music festival.

WMAS allows for easier coordination and greater allocation efficiency in using multiple devices over a relatively wide radio channel bandwidth (WMAS is specified for 6,7,8,10,20 MHz channels) compared to traditional narrowband 200kHz audio channels. WMAS is particularly effective for larger scale PMSE users managing large numbers of devices. It allows statistical multiplexing, and it can optimise for devices with differing performance requirements. WMAS also promises a reduction in fade margin to achieve wireless link Signal to Noise Ratios (SNR) by exploiting the frequency diversity afforded by a wideband radio channel. Whilst it is still technically possible to encounter flat fading radio channels in some environments, where frequency diversity may be less beneficial, overall, there should be a meaningful net gain in Spectral Efficiencies.

45 RSPG, 2017

Views on the size of the potential efficiency gains vary, with a consensus that gains should be meaningful but not revolutionary. For example, ETSI predicted that efficiency could increase by about 50% in comparison to narrowband systems[46]. Other commentators suggested that WMAS could lead to a rough doubling in the number of audio channels that could be supported in one UHF 8 MHz channel bandwidth, although the exact mix of wireless device types will be a factor. Sennheiser publicly states there would be a "substantial gain in spectral efficiency at large events"[47]. Once WMAS starts being deployed by the PMSE industry, empirical evidence of PMSE licence data will become available and should inform us of the spectral efficiency gains.

However, WMAS is still an emerging technology, and it may still take several years for WMAS-compatible equipment to diffuse through the user base, although this is aligned with the timeline which this report is concerned with, i.e. UHF beyond 2034.

4.6 Recent technological advances – 5G for PMSE

Research was carried out on the use of 5G for audio PMSE[48]. The key performance requirements that 5G will have to meet are the demanding levels of latency and reliability necessary for the use of audio PMSE in live and recorded performance. Latency is critical because if it rises above a certain level, musicians will be unable to synchronise with other performers. Reliability is essential for live performances, because any failure, even temporary, may be noticed by the audience and detract from their enjoyment, with a knock-on effect on what audiences will be willing to pay.

Nokia and Sennheiser conducted a testbed for PMSE over 5G in 2021[49]. They reported a 7ms application latency for 2-way transmission from microphone to receiver unit and back to the artist's IEM. Although, the required application latency for PMSE is 4ms or less, Nokia and Sennheiser concluded that 5G held promise for PMSE, though further improvement was necessary to prove it could meet the latency requirements. They also noted that commercialised equipment may offer superior performance to the equipment used in the testbed and this would help to bridge the gap.

Nokia and Sennheiser also noted that 3GPP standardised URLLC enables the reliability requirements for PMSE to be met with Release 15 providing successful packet delivery of 99.999% or higher and work was continuing in Release 16 to reach 99.9999%.

In practice, several commercial issues would need to be resolved to enable PMSE to move to 5G, including whether it would be provided by a "slice" from the public mobile operators or whether a private 5G network would be used in a studio or theatre environment. However, the consensus from our interviews suggested that PMSE using 5G was an unlikely candidate for audio PMSE, although private 5G has been used for video delivery for broadcast productions, including the televising of the Queen's State Funeral.

4.7 Prospects for additional spectrum bands for PMSE

An alternative to deploying new technologies to provide more capacity for PMSE would be to identify new spectrum bands. Any new spectrum would have to lie in the sub-1.5 GHz range in order for audio devices to function acceptably. This is because many audio PMSE equipment is body worn and, as a result, radio waves interact with the human body. At frequencies above 1.5GHz, this interaction can start to lead to problems with the directivity of the signal and body absorption. Frequencies in the VHF range tend to have manmade environmental Noise levels and the antenna wavelength sizes become large and sub-optimal within a constrained wireless device form factor such as a microphone. In many ways, UHF is the optimal band for professional audio PMSE.

International harmonisation is also an important factor in introducing new bands for audio PMSE, especially for international PMSE users. Manufacturers are less likely to supply equipment for spectrum that is only available in a few countries. Moreover, any equipment that is produced for a limited market will be relatively expensive due to the weaker economies of scale. This phenomenon is apparent in the UK, where the UK has pioneered the 960-1154 MHz band for audio PMSE (a

[46] ETSI TR 103 450 V1.1.1 System Reference document (SRdoc); Technical characteristics and parameters for Wireless Multichannel Audio Systems (WMAS), 2017, https://www.etsi.org/deliver/etsi_tr/103400_103499/103450/01.01.01_60/tr_103450v010101p.pdf

[47] https://www.sennheiser.com/en-gb/learn/wmaspages/wmas-interview-wmas-experts

[48] E.g. the PMSE-xG project, http://pmse-xg.research-project.de/index.html

[49] Nokia, Sennheiser white paper, January 2021, "Low Latency 5G for Professional Audio Transmission" https://www.bell-labs.com/institute/white-papers/low-latency-5g-professional-audio-transmission/

few other countries are considering following suit). Although there is some professional use of the band in the UK, take-up is low due, in part, to the cost of the equipment.

5. Mobile – key trends and issues

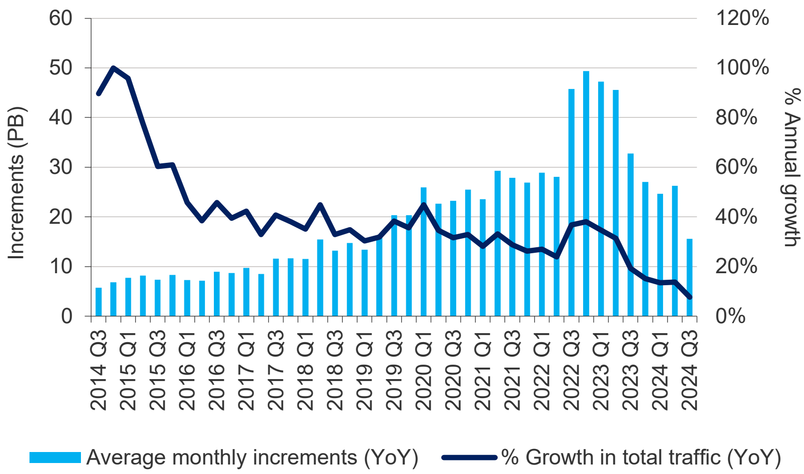
5.1 Mobile data consumption trends

Data consumption volumes published by Ofcom[50] indicate that mobile network traffic in the UK has doubled within the three-and-a-half years between Q1 2021 and Q3 2024. A key question, now, is whether this explosive growth is likely to persist during the next decade.

According to some commentators, mobile network data traffic growth is slowing down, hence the rising pressure on networks is abating. While it is true that growth is slowing in percentage terms, it is continuing to grow in absolute terms.

It is not surprising that percentage growth rates decline year-on-year, as the annual baseline increases. This is a consequence of simple mathematics: a growth of 10 from 10 to 20 represents a 100% increase, whereas the same absolute delta of 10 from 100 to 110 is a 'mere' 10% rise. This effect is broadly visible in the 10-year trend depicted in Exhibit 9 below.

Exhibit 9: UK mobile data: total % growth and annual traffic increments

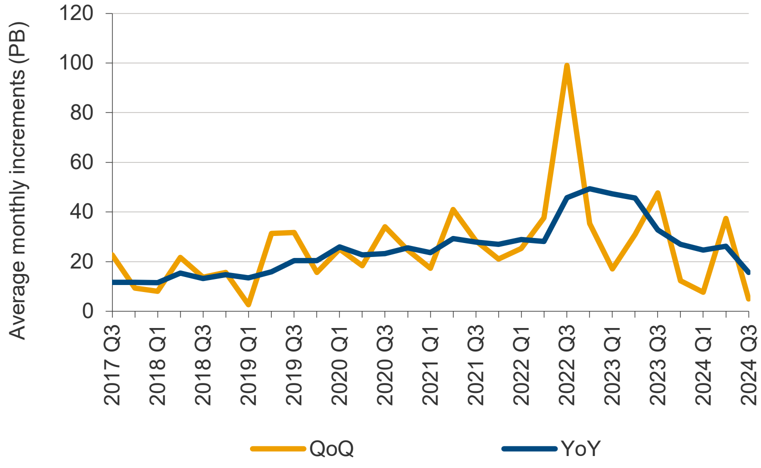


Source: Coleago based on Ofcom data

The graphic above shows YoY (year-on-year) trends – i.e. growth over the preceding 12 months for each quarter. It may suggest that absolute growth in consumption intensity peaked in 2023 but is now in decline. However, we should be careful about drawing such conclusions. Traffic trends are noisy, and this apparent easing of growth follows an unusually large spike in Q3 2022, as shown in the QoQ (quarter-on-quarter) data below:

50 Ofcom 'Connected Nations Report 2024'.

Exhibit 10: Quarterly and annual mobile data traffic increments



Source: Coleago based on Ofcom data

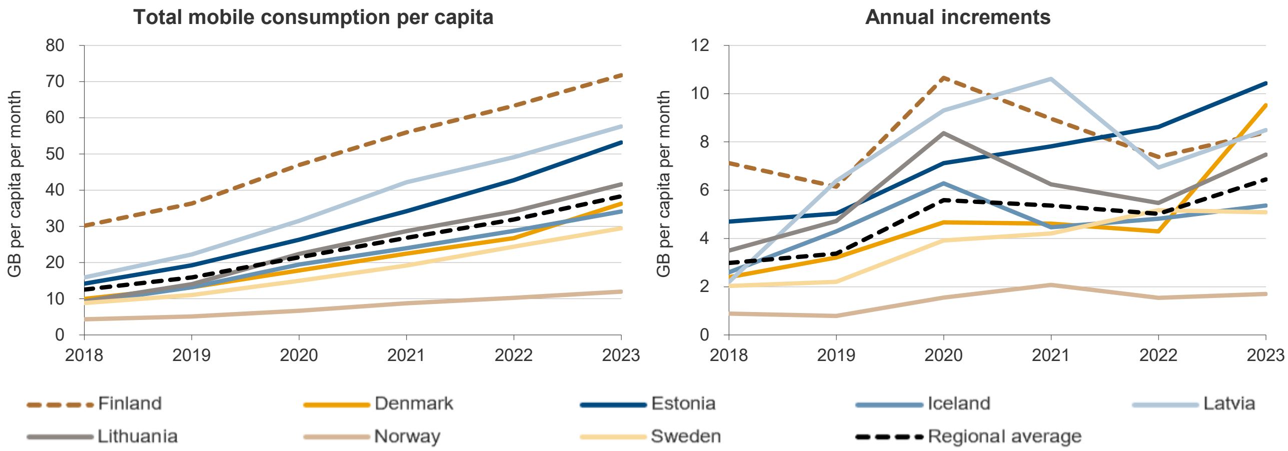
The spike in Q3 2022 appears to coincide with the end of the pandemic, with people finally spending more time outdoors, driving higher mobile consumption. The deployment of 3.5 GHz spectrum may also be a contributing factor. Spectrum in the 3.6-3.8GHz range was auctioned in 2021, and it takes time to deploy as well as for compatible devices to diffuse throughout the mobile consumer base.

What is clear from the data, however, is that a 'zig' in any quarter tends to be followed by a 'zag' in the next one or two periods – and another 'zig' thereafter. A positive outlier such as that in Q3 2022 may be seen as a 'catching up' on suppressed growth in previous quarters as well as an early redemption on future growth potential, resulting in moderate further increases immediately following it.

It would have been premature to call the end of mobile telecoms history in Q1 2019 (which saw the lowest absolute growth in the last seven years). Likewise, the dip in growth in Q3 2024 (our most recent data point) should not be read as an inflection in the overall trend: a rebound in subsequent quarters seems more likely than a permanent easing of growth.

The overall trend towards increasing absolute growth is also apparent in countries with far higher mobile data consumption intensities than the UK – such as in the Nordics, where the regional average approached 40GB per capita per month in 2023, versus 17GB per capita per month projected by the GSMA for the UK by the end of 2024:

Exhibit 11: Growth in Mobile data consumption in Nordic countries



Source: Coleago based on data from PTS

Across the Nordic region, average absolute annual increments (increases in GB consumed per capita per month) in 2023 were more than double the size of those in 2018. If anything, the growth curve in the UK lags this Nordic benchmark, and it would be unusual if absolute growth were to subside in the UK while it continues to accelerate elsewhere.

It is also important to note that mobile data consumption is not independent of supply. Inferior quality of experience due to network congestion or lack of coverage is bound to be a limiting factor. Latent demand is hard to quantity, but anecdotal evidence obtained during our stakeholder interviews as well as during our separate engagement with mobile operators overseas suggests it is invariably strong. Operators express surprise at how quickly newly deployed capacity is utilised – often significantly faster than local traffic levels would lead them to anticipate.

This is the case especially when low bands are 'lit up', providing deeper indoor coverage. It appears that when consumers *can* obtain a good connection, they use it. And it seems reasonable to suppose that they use it because they have a *need* for it.

Key drivers of mobile data traffic growth include:

- Increased smartphone penetration (especially 5G) and increased video streaming per smartphone, enabled by improved network quality and larger/unlimited data plans
- Increased resolution of video streaming and gaming, driving higher data consumption per hour of use
- Increased substitution of fixed broadband by mobile

The rise in average video resolutions may be the single largest contributor. In 2018, most mobile video was streamed at low resolutions between 360p and 720p[51] – largely due to restrictions by content providers and operators, as well as users selecting lower bit rates due to tighter data allowances. These constraints are rapidly disappearing, with data allowances increasing dramatically or becoming unlimited. Raising the average from (say) 480p to 720p would drive an almost fourfold increase in mobile video traffic per hour of consumption[52].

Improving mobile network performance and increasing data allowances are likely to drive wider substitution of fixed broadband by mobile. This may play out at the level of adoption, particularly among people who cannot afford both mobile as well as fixed broadband subscriptions. It may also play out in relation to usage levels – with data consumption needs increasingly being met on the move. Growth in mobile data use from connected (IoT) devices will add to the overall upward pressure.

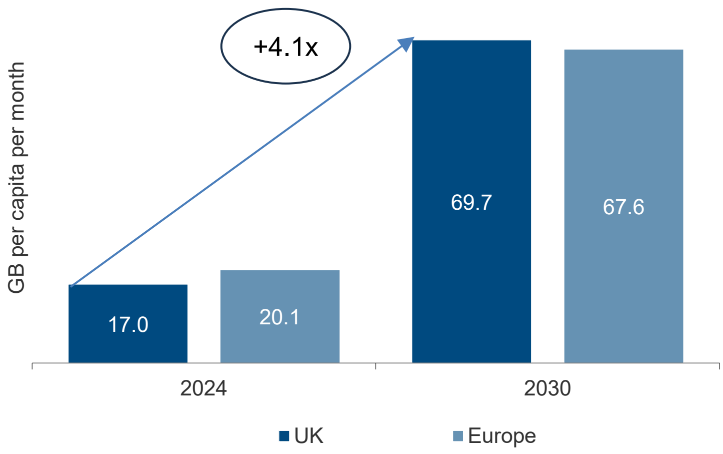
According to the GSMA's forecasts[53], total mobile network consumption in the UK will grow by a factor of 4.1x between 2024 and 2030. This compares with 3.4x for Europe. On a per-capita basis, consumption in the UK has some catching up to do, and the GSMA projections suggest that the UK will overtake the regional average, slightly surpassing it in 2030. This implies a 24% CAGR for the UK versus 28% for Europe.

51 Source: Ericsson Mobility Report, 2018.

52 See 'Mobile Network, Spectrum, and Public Policy Outlook to 2030', Coleago Consulting, July 2024.

53 See GSMA the Mobile Economy Europe 2025, January 2025.

Exhibit 12: Projected mobile data consumption per capita (GSMA)



Source: Coleago based on GSMA projections

To achieve this, the UK would need to add an average of 0.7GB to monthly consumption per capita in each of the 720 months between 2024 and 2030. This is 1.6x the average monthly increment between Q1 2021 and Q3 2024 – which is not implausible in light of the accelerating absolute growth observed in the Nordics (with annual increments more than doubling between 2018 and 2023).

Whether or not the GSMA is proven right on fourfold growth by 2030 remains to be seen, but even a mere doubling of traffic over this horizon would add substantial pressure on mobile networks. If the GSMA's projections prove wrong, it seems more likely to us to be on timing than on quantum. Either way, our assessment is that on a balance of probabilities, very large increases in mobile consumption remain to be expected in the decade ahead.

The increasing burden on mobile networks is compounded by the evolving Quality of Service (QoS) needs of mobile users. Live video communications and streaming, as well as emerging IoT and Mixed reality ("XR") applications require ever more reliable connections, with high throughputs and low latencies. Significantly more capacity is needed to carry a given amount of traffic with high QoS levels than to transmit the same amount on a 'best effort' basis.

5.2 IMT demand for indoor and wide area cell-edge capacity

Due to its superior propagation characteristics, conferring significant wide-area and indoor coverage benefits, low band spectrum is a very attractive resource for mobile communications. Industry stakeholders that we interviewed during this study refer to it as the "Heineken effect": low bands address demand that no other bands can reach[54].

In our 2022 report for the UK Spectrum Policy Forum on the 'Future Utilisation of the 470-694 MHz band'[55], we highlighted the importance of the 800 MHz band in the 4G era. Based on crowdsourced network data published by Tutela, we estimated that the 800 MHz band carried over a third of total 4G traffic in the UK in 2020 – despite accounting for 13% of 4G-compatible bandwidth at the time. Given that traffic is always pushed to higher bands, when possible, this yields a good indication of the proportion of total demand that cannot be served with mid band frequencies.

The addition of 2 x 30 MHz at 700 MHz following the 2021 award increased total sub-1 GHz holdings by 50%[56] – while the addition of 390 MHz at 3.5 GHz implied an increase of 88% in downlink bandwidth above 1 GHz (taking 4G-compatible spectrum as a baseline). Furthermore, there is limited scope to improve spectrum efficiencies in low band by deploying

54 The reference is to the iconic advertising slogan "Heineken refreshes the parts other beers cannot reach," created by Terry Lovelock in 1973.

55 'Future Utilisation of the 470-694 MHz Band in the UK', *ibid.*

56 We exclude the 20 MHz of 700 MHz SDL (supplementary downlink) spectrum that was awarded to BT/EE from this calculation, on the basis that prospects for a viable ecosystem in this band seem remote. Since very few countries have awarded this resource, there appears to be insufficient scale to drive support by equipment and device manufacturers.

higher order MIMO (Multiple-Input/Multiple Output) antenna systems, due to antenna size constraints. In contrast, massive MIMO is available in higher mid bands, enabling increases in capacity per MHz ranging from around 2.6x for 32T MIMO to 4.2x for 128T MIMO. Low band deployments with 4T at the base station are feasible today, but the net capacity uplift is modest given that most mobile devices only support 2T antenna systems for low band (again, due to size constraints). Consequently, low bands account for a dwindling percentage of total potential site capacity.

There are other measures that operators can pursue to optimise efficiency of existing spectrum holdings, such as band defragmentation. Significant progress has already been achieved in this area, notably in the 900 MHz band. Section 8 discusses these in greater detail, with an assessment of further options. This is a case of desirable if modest improvements relative to the scale of the issues at hand.

As total demand grows, so does demand (deep) indoors and in wide areas at the cell edges. With two-, three- or fourfold growth in the near to medium term, mobile consumer needs in these hard-to-reach areas are becoming increasingly difficult to meet without additional low band capacity.

Low band frequencies are scarce, and there are few substitutes. Ofcom is currently consulting on the further release of 25 MHz Supplementary Downlink spectrum in the 1400 MHz band[57]. If we were to treat this as a substitute for low band, an extra 25 MHz would represent a net increase in downlink bandwidth of around 20%. This could be a welcome addition: while the propagation characteristics at 1400 MHz fall far short of those between 600 MHz and 900 MHz, they are superior to those at 1800 MHz and above. A further release to IMT in this band may relieve some of the pressure, but it would be unlikely to eliminate it.

Wi-Fi is also often seen as a possible substitute where indoor mobile coverage is lacking. But a majority of consumers will already have Wi-Fi at home, and they will likely have had it for many years. There is no doubt that Wi-Fi carries as very large proportion of total data traffic from smartphones and other mobile devices. The issue is with the indoor traffic that Wi-Fi does *not* carry, and this remains persistently large. Part of the issue may relate to indoor connectivity outside consumers' primary (work and/or home) locations. Even where Wi-Fi coverage is available, getting connected (outside users' primary locations) is often cumbersome. Nor does Wi-Fi solve consumer needs for ubiquitous connectivity whilst on the move, such as when they travel by rail or by car through more sparsely populated areas.

Direct-to-device (D2D) connectivity from High Altitude Platforms such as LEO satellites, finally, may help bridge the geographic coverage gap on land and on sea. But the capacity that these can deliver is limited, curtailing their potential for mass market broadband connectivity. In December 2024, for example, Starlink paused new customer sign-ups in London and most of the South-East of England, as demand already appeared to exceed available capacity[58].

Finally, low band insufficiency could in principle be mitigated through network densification (cell-splits). However, there are multiple issues with this. First, interference limits the scope for low band densification in urban areas given the short inter-site distances. Secondly, finding suitable site options (both in urban and rural environments) poses a challenge, which is exacerbated in the UK by a lack of supply from private landlords who, under the UK code provisions have fewer incentives to make real estate assets available. Third, cell splits are costly, and higher network costs are prone to be passed on to consumers in the form of higher retail prices and/or reduced investment in other areas. A pass-through of inefficiencies is more likely when all market participants are subject to financial pressures due to low returns on invested capital.

Our engagement with operators both overseas and during this study leaves us in no doubt that demand for additional low band capacity is strong across the industry. But one should not look at operator willingness to pay for spectrum as an indication of the value that it delivers. Perennially low returns on invested capital against a backdrop of declining real-term industry revenues constrain operators' collective *ability* to pay for spectrum.

The bulk of the value from mobile accrues to consumers rather than to operators. The explosive growth in mobile broadband adoption and use at ever declining unit prices, over many years, imply very large increases in consumer welfare – while producer surplus stagnated or declined. Through its indirect impact on economic productivity, increased output from the mobile sector also benefits society as a whole. Accordingly, increased low band capacity for mobile would be highly desirable from a societal perspective.

[57] Ofcom consultation 'Award of the 1492-1517 MHz spectrum for mobile services', due to close on 25 April 2025. 25 MHz.

[58] See 'Starlink at capacity in the South East', ThinkBroadband.com, 31 December 2024.

5.3 The IMT case for additional UHF spectrum

Absent adequate alternatives, additional UHF spectrum appears to be the only suitable resource with prospects for a strong global IMT ecosystem (see Section 7.9 for a discussion on current and future device support for IMT600).

A substantial tranche of clean UHF spectrum would also support the future roll-out of 6G. The introduction of new technologies is facilitated by a dedicated low band for coverage in conjunction with at least one dedicated mid band for capacity.

In the 4G era, the coverage layer was provided by 800 MHz, with 4G capacity delivered at 2600 MHz as well as re-farmed 1800 MHz. Further resources were added over time with refarming of 2100 MHz and 900 MHz. The initial introduction of 5G was supported by 700 MHz for coverage and 3.5 GHz for capacity. Increased refarming of 4G to 5G refarming will take place as the proportion of 5G-enabled traffic allows. Dynamic Spectrum Sharing (DSS) allows resources to be apportioned flexibly between 4G and 5G, although DSS does introduce overheads that bear on performance and net total capacity delivered.

For 6G, one may envisage UHF spectrum in conjunction with the Upper 6 GHz band as a relevant spectrum pair. This was suggested by stakeholders during our interviews, and this combination is viewed as the most plausible for 6G by operators that we have spoken with overseas. A successful introduction of 6G in the UK is seen as a key enabler of national prosperity. The UK Wireless Infrastructure Strategy makes the case that 6G protects “our position in an increasingly competitive global economy, securing the UK’s international competitiveness and ensuring that our wireless future works for British people and businesses in every corner of the country”[59].

Similar sentiments are expressed in the Letta report[60], within an EU context: “Crucial to fully realising [key cross-sector transformations] will be the deployment of 5G/6G mobile connectivity augmented by artificial intelligence (AI) and cloud solutions”; “Technologies such as 5G (6G in the future), Internet of Things, web3.0, edge-cloud computing or artificial intelligence will create entirely new economic opportunities”; and “A dynamic approach to consumer welfare implies first of all the possibility to choose and to benefit from technological innovations and advanced services”.

According to Ericsson[61], “The first commercial 6G services are expected around the year 2030, with pre-commercial trials expected from 2028 and early proof of concepts expected even earlier”. A key question is whether additional UHF spectrum could be made available soon enough to meet IMT needs.

We put this to operators during our stakeholder interviews. The common response was that while delayed access to additional UHF bandwidth would be suboptimal, it would not represent “mustard after the meal”: it is very much a question of “better late than never”. Similarly, operators would far prefer to face constraints on UHF use at certain locations and/or at certain times than never to be able to use it anywhere.

59 See the UK government Policy Paper, April 2023.

60 ‘Much more than a market – Empowering the Single Market to deliver a sustainable future and prosperity for all EU Citizens’, Enrico Letta, April 2024.

61 See Ericsson’s online article ‘6G timeline: growing from 5G to 6G’.

6. Fixed broadband and FWA – key issues and trends

In this section, we consider developments in the fixed and fixed-wireless access (FWA) broadband sector. The availability and adoption of broadband is relevant to our analysis on two accounts:

- It bears on the scope to substitute DTT with IPTV
- It may also offer a degree of mitigation for mobile low band insufficiency, by enabling indoor coverage solutions

6.1 Broadband availability

According to Ofcom's latest Connected Nations Report[62] around 99% of residential and commercial premises have access to 'decent' fixed broadband – defined by Ofcom as fixed connectivity with speeds of at least 10Mbps downlink and 1Mbps uplink. With FWA provision from MNOs and WISPs, total broadband coverage rises further, with just around 58,000 or 0.2% of dwellings in the UK unable to access a decent connection[63]. Ofcom anticipate this to reduce to 48,000 by December 2025. The number of actual households without decent access will be lower, given the ~92% occupancy rate of dwellings across the UK, and it is set to fall further, with a ~20% planned increase in FWA masts between May 2025 and May 2027.

Exhibit 13: Fixed broadband availability across the UK

	Gigabit-capable (residential)	Full fibre (residential)	Superfast (residential)	Unable to get decent (all properties)
UK	83%	69%	98%	0.2%
Scotland	77%	62%	96%	0.5%
Northern Ireland	94%	93%	98%	0.2%
Wales	74%	68%	96%	0.5%
England	84%	69%	98%	0.1%

Source: Ofcom Connected Nations Report, December 2024

10Mbps connections should in principle be sufficient to support at least SD quality IPTV. According to IPTV Express[64], the standard resolutions for IPTV are 720p, which requires 2-10Mbps, and 1080p which requires 10-20Mbps. Uswitch claims that a minimum of 3Mbps is needed for SD streaming, 5Mbps for HD, and a minimum of 25Mbps for 4K[65].

With availability of decent broadband for around 99.8% of households, IPTV appears to be an almost universal (if not always ideal) option, Connectivity speeds significantly above 10Mbps would certainly be preferable – especially when multiple devices make concurrent use of the available bandwidth.

Superfast broadband (with downlink speeds of at least 30Mbps) already reaches 98% of premises, and according to planned deployments, access to gigabit-capable services will reach 93% by May 2026 and 98% by May 2027 (with 5.4%

[62] https://www.ofcom.org.uk/phones-and-broadband/coverage-and-speeds/connected-nations-2024/

[63] The Connected Nations Report specifies that around 0.2% of *all* properties (commercial and residential) are unable to get decent broadband, however the quoted figure of 58,000 corresponds with 0.2% of the 29.9m dwellings (based on data from the ONS, Scottish Government and Northern Ireland Executive).

[64] 'How Much Bandwidth Does IPTV Consume', March 2024 (available at: https://iptvexpress.uk/how-much-bandwidth-does-iptv-consume-iptvexpress-uk/).

[65] 'What broadband speed do I need for streaming?', Nick Baker (Senior Editor), December 2024 (available at: https://www.uswitch.com/broadband/guides/broadband-for-streaming/).

implied annual growth). Closing the residual coverage gap becomes increasingly costly and difficult, as it involves penetrating ever more remote areas. Nevertheless, given the high projected growth rates to 2027, it seems plausible that gigabit-capable coverage will exceed the current (~98.5%) reach of digital PSB multiplexes by 2034 if not before the end of the decade. In short, (future) fixed broadband infrastructure does not appear to be the main problem as far as potential IPTV substitution of DTT is concerned –albeit one relevant stakeholder did suggest that with respect to substituting DTT with IPTV and traffic absorption into broadband networks, consideration will need to be given to aspects such as quality, reliability and network traffic around of peak events being appropriately managed.

6.2 Broadband exclusion

Broadband exclusion, on the other hand, certainly *is* a major barrier to IPTV adoption. Despite the high availability, the number of households that fail to take up broadband services is still significant. According to consumer research published in Ofcom's Technology Tracker 2024[66], 5% of households (~1.4 million) do not have access to the internet via any device at home. The corresponding figure is 13% among survey respondents aged 65 and above, and it is 22% among households with an income below £10,400 per annum.

Within the excluded group, only 10% of respondents stated that they were either certain or likely to get connected within the next 12 months. Reasons given for not getting connected include:

- "Not interested or no need": 69% of respondents
- Cost of broadband adoption and use was cited as an issue by 27% of respondents
- "Getting online in too complicated": 9% of respondents
- "Using the internet is too complicated": 13% of respondents

Accordingly, lack of interest is the dominant cause for non-adoption of broadband at home, and it may be the most difficult issue to overcome. Cost is a factor in less than a third of cases. A lack of digital skills is the third most prevalent reason given for not connecting.

In the cases for which broadband is solely needed to enable TV consumption, however, these issues could yet be surmounted. One-off IPTV installation visits could address a lack of digital skills. Where the affordability of broadband connectivity is the main obstacle, social tariffs or subsidies may be envisaged. The costs associated with IPTV transition in these instances could plausibly be covered by the spectrum fees paid by alternative users of any reallocated UHF bandwidth.

Broadband exclusion leans heavily towards more vulnerable demographics (low-income households, older age groups and people with poor digital skills). For many of these people, DTT is the only window to the wider world. Losing access to broadcast content would impose a high social cost on them. Some commentators have argued that vulnerable demographics are less likely to have access to large screen televisions and are therefore potentially less interested in higher resolutions. A standard definition night-light service may therefore be appropriate. This will need further investigation.

[66] See https://www.ofcom.org.uk/siteassets/resources/documents/research-and-data/data/statistics/2024/technology-tracker/technology-tracker-2024-data-tables.pdf?v=374153

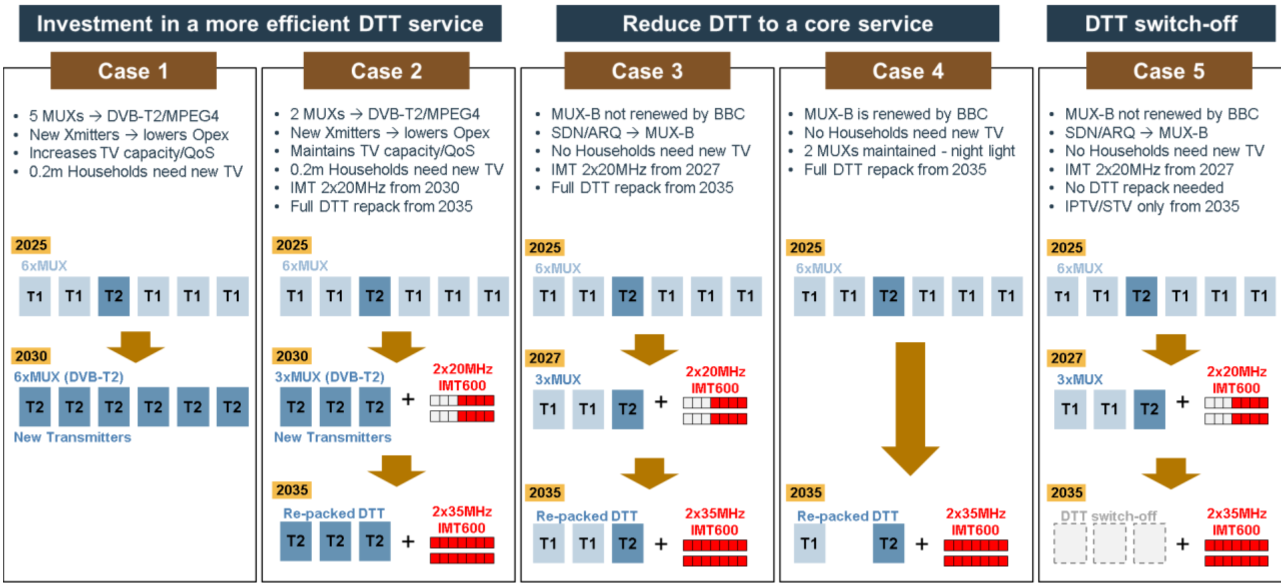
7. Analysis of Ofcom's future of TV distribution scenarios

DTT in the UK could evolve in dozens of different ways over the next decade, and the evolution journey and choices will be influenced by a myriad of factors. Ofcom's Future of TV Distribution[67] concluded three different broad approaches could be taken. We take these three approaches and expand these to five possible evolution cases in our study.

Cases 1 and 2 fall under the Ofcom approach for investing in the DTT network for a more efficient service. IN both cases, the introduction of DVB-T2 also includes the refresh of transmitter equipment to also deliver a more energy efficient service.

Case 1 is the case where the current five Multiplexes using DVB-T with MPEG2 video coding are upgraded to DVB-T2 with AVC/MPEG4 video coding. This case boosts TV Channel capacity (quantity of channels) and/or quality of service (e.g. HD channels) significantly within the same DTT frequency allocations. A key motivation for this Case 1 is to also take advantage of the latest generation of much more energy efficient DVB-T2 transmitters to reduce operational costs so a more sustainable network can be achieved, in business terms. There is no IMT600 spectrum carved out and hence also reflects a case where mobile operators in the UK and in Europe may also not need extra low band spectrum for whatever reason such as demand for spectrum reducing or delayed European stakeholders support for the band.

Exhibit 14: DTT evolution cases considered



Source: Coleago Consulting

Case 2 also falls under Ofcom's approach for investing in a more efficient DTT service, where TV channel capacity and quality mix is maintained using three Multiplexes all using DVB-T2 with AVC/MPEG4 video encoding. In this Case 2, with new transmitter equipment, energy costs can be reduced further. Case 2 also provides an opportunity to release some IMT600 spectrum whilst maintaining existing agreed DTT UHF channel allotments and hence not require any major re-engineering or spectrum coordination efforts. Case 2 however assumes that by 2035 a full UHF channel re-pack can be delivered releasing a full 2 x 35 MHz IMT600 band plan most likely aligned with some European wide consensus for IMT600. In both cases 1 and 2 there is a need to also invest in upgrading some households which have DVB-T only receivers by 2030 also. As there would be only be 0.2m Households with primary TV sets by 2030 we felt that this could be achieved much earlier than 2035.

It should be noted that a transition to DVB-T2 does not require a full new transmitter. The existing Power Amplifier components of the existing transmitters could also be used where only the baseband and exciter components of the DTT transmission line up need replacing. We however decided not to assess these DVB-T2 (without new Transmitter) upgrade cases since Ofcom's future of TV distribution report made several references to the prospect of both spectral and energy efficiencies.

[67] https://www.ofcom.org.uk/tv-radio-and-on-demand/public-service-broadcasting/future-of-tv-distribution/

Case 3 falls under the Ofcom approach for reducing DTT to a core service. In this Case 3, there is no investment made into the DTT network or in upgrading TV sets. Case 3 also assumes that the BBC decides not to renew its MUX-B Multiplex licence and hence reflect a market driven decline in DTT demand. Case 3 also presents a case whereby the Commercial Multiplex operators can consolidate from three DVB-T/MPEG2 Multiplexes onto the single vacated MUX-B Multiplex and take advantage of the enhanced coverage. There are no domestic TV upgrades needed for Case 3. A partial IMT600 dividend is possible from 2027, followed by a full DTT channel repack delivered from 2035.

Case 4 also falls under Ofcom's approach for reducing DTT to a core service, but here we assume a more straightforward transition from six Multiplexes to two Multiplexes from 2035. As such, this case does not require changes to Multiplex licences. A full DTT channel repack is delivered from 2035 as clearance for IMT600 services.

Finally, case 5 follows the same trajectory as case 3 but plans for complete DTT switch-off from 2035. In case 5, it's assumed that IPTV becomes the dominant TV distribution method replacing DTT altogether. From 2035 there is no need for any DTT re-pack and IMT600 can be made available as soon as DTT sunsets.

As can be appreciated, dozens of cases could be created by varying decisions such as whether:

- The BBC renews its MUX-B licence at the end of 2026 or not
- The BBC renews its MUX-1 licence at the end of 2027 or not (although we expect they will renew)
- The BBC changes its Royal Charter in 2027 for delivery of services over DTT
- Changes can be made to Multiplex licences in the event of investment, or departure of MUX operators
- MPEG4 upgrade rather than DVB-T2 with MPEG4 should be considered
- Investment cases only upgrading the baseband/exciter components to re-use existing Power Amplifiers
- Cases involving 4x MUX outcomes should be considered
- Cases involving HEVC video coding should be considered
- Cases involving widescale 5G Broadcast demand evolves by 2035

7.1 Cost modelling

For this study we have not engaged in a formal cost benefit analysis of spectrum value where more detailed costs are required. Such a Cost Benefit analysis may form part of future studies led by DCMS or Ofcom and be informed by studies such as this report.

During this study we were not able to establish detailed costs of capital equipment such as new DVB-T2 transmitters and their required power ratings for the 80 main DTT broadcast sites, nor establish current DTT operational and energy costs. Estimates for such costs would have been best gleaned from Arqiva for this study. However, Arqiva did not participate in this study. As such, we used public domain material and our own assumptions to arrive at high-level estimates for costs associated with each of the five future UHF evolution cases.

7.1.1 DTT network energy costs

The energy costs modelling applies to all cases for the three Ofcom scenarios. The electricity energy is a significant Opex cost component in running the DTT network. Arqiva have publicly stated these challenges in their recent Financial Statements[68]. In our study we assume any new high-power DVB-T2 transmitter equipment will be at least 50% energy efficient from 2025 based on public domain literature[69]. We also assume that the existing DVB-T transmitter equipment may be around 25% energy efficient having been deployed during the 2000s. This is also supported by Arqiva's calls for inputs to Ofcom's Future of TV Distribution report[70].

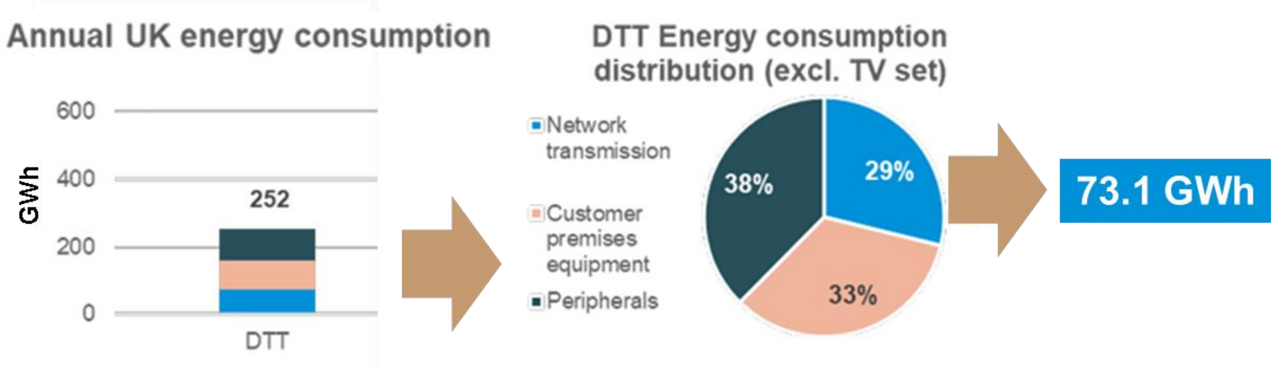
[68] https://www.arqiva.com/about/financial-reporting/group-financial-results/

[69] https://kvantefir.com/products-en/digital-dmv-en

[70] Section 4.47 of https://www.ofcom.org.uk/siteassets/resources/documents/consultations/category-1-10-weeks/269636-call-for-evidence-future-of-tv-distribution/future-of-tv-distribution-report-to-government.pdf

Ofcom commissioned a study into the energy requirements associated with DTT and Over-The-Top (OTT) delivery of TV services[71]. Data was provided by Arqiva for this study which indicated that 252GWh of energy was consumed during 2021, of which 29% was associated with the DTT network. This suggests that there was 73.1GWh of energy consumed by the DTT network during 2021. We assume that this figure will not have changed much as this relates to power consumption and the DTT network has not materially changed since 2021.

Exhibit 15: DTT network energy consumption (2021)



Source: Ofcom, Arqiva and Carnstone

We also benchmarked this figure using a 'bottoms-up' energy model where we estimated the DTT energy demand from each of the 80 main broadcast sites. In this 'bottoms-up' model we estimated the RF power ratings of the existing five DVB-T and one DVB-T2 transmitter unit by taking Effective Radiated Power (ERP) per Multiplex data from Ofcom[72], together with estimates of RF feeder and combiner losses, and estimates of antenna gains at the 80 main broadcast sites. Using the estimated RF power ratings along with our 25% power efficiency assumptions we arrived at around 65GWh as an estimate for the 80 main broadcast sites. The energy requirements from repeater stations and any cooling systems were estimated at another 10%, which meant our bottoms-up estimate was 71.5GWh.

The future cost of energy is very difficult to predict and a major sensitivity in our cost model given the huge energy requirement of running a DTT network. Although commercial electricity rates increased significantly between 20-40% from 2021-2023 (Ofgem), they stabilised from 2024. However, for our modelling we have assumed Electricity RPI increases at 4% per year over the long term which remains above expected general price inflation rates. We assume a commercial rate of £0.25/kWh taken from public domain sources for large business users. Finally, we assume the energy costs associated with an upgrade to the DTT network are seen the following year to reflect that deployment may take more than one year across the DTT network.

7.1.2 DVB-T2 new transmitter costs for DTT network

The DVB-T2 equipment costs modelling applies only to the first Ofcom scenario where there is investment made into the DTT network. We assume a full replacement of transmitter equipment in our cases where the costs of DVB-T2 transmitter equipment includes exciter/baseband, and Power Amplifier components. We do not consider any cases where partial upgrades are carried out such as keeping existing Power Amplifiers.

As a guide, the costs of partial upgrades of DTT equipment have been made in public domain statements from Ofcom[73] and Arqiva[74] associated with the 700 MHz clearance activities. These costs related to upgrading to DVB-T2 only (and not upgrading of the Power Amplifiers). Cost estimates ranged between £30M for upgrading two Multiplexes to DVB-T2 to £50M for upgrading five Multiplexes to DVB-T2 across the DTT network. Whilst the Ofcom and Arqiva sources did not break down costs further, we expect that most of these costs are for the exciter, baseband components and

[71] Https://www.ofcom.org.uk/siteassets/resources/documents/research-and-data/technology-research/2022/carbon-emissions-of-streaming-and-digital-terrestrial-television-3.pdf

[72] https://www.ofcom.org.uk/tv-radio-and-on-demand/coverage-and-transmitters/transmitter-frequency/

[73] Decision to make the 700 MHz band available for mobile data – statement from Ofcom (19 Nov 2014)

[74] 700 MHz High Level Estimate Single Hop & PSB MFN/COM SFN Plans (Arqiva – May 2014)

installation/commissioning costs. We would also expect these costs to have reduced due to capex erosion, competition, scaling, efficiencies and maturity since 2014.

There is some public domain 2019 pricing information for full DVB-T2 transmitters from Transcom Corporation[75] which quotes US$205K for a 5kW DVB-T2 transmitter without digital mask filter. Pricing for different power transmitters scale linearly for high power variants which is to be expected since higher powers are achieved through coherent combining of multiple parallel Power Amplifiers. Based on published DTT Multiplex ERP figures, our estimate of antenna gains and feeder losses for the top 80 main DTT sites, we estimate that the capital costs for installing five new DVB-T2 transmitters for all main DTT sites would be between £80M and £130M as of 2025. For the purposes of this study, **we assume £25M per Multiplex for simplicity**. We assume 3% capital price erosion per year and there would be no changes to frequencies, antennas, combiners, feeders, buildings or cooling systems. Only Arqiva would be able to provide an accurate view of capital costs and as we did not have access to Arqiva for this study our £20M per Multiplex figure should be treated as illustrative only and not for any financial planning. The costs associated with repacking UHF channels for clearance of 600 MHz is discussed later and treated as a separate capital cost item.

We do not include any capital costs associated with upgrading video encoders to MPEG4/AVC. The BBC will have such encoders as they already encode their BBC-B Multiplex with MPEG4/AVC, and as such encoding load is simply scaled. For other content providers and/or Multiplex operators (Arqiva, SDN, D3&4) our limited research in this area suggested that costs may only be a few £100k's and therefore in the noise regarding the overall costs.

The DTT investment model to date has broadly been aligned on Arqiva making an investment and subsequently charging the Multiplex operators an annual fee, with a business case for payback on investment over a long-time horizon such as 30 years. Given the very real situation that the DTT platform may be around for the next 10-20 years, the question on investment and payback on investment is critical. However, who bears the cost of these investment costs and other capital equipment upgrade costs is not the subject of this study or report, although any investment would likely be a mix of Arqiva, content providers, future auction proceeds, and other investors which could include Government, and transacted in the form of various future payments between stakeholders.

7.1.3 DVB-T2 equipment costs for TV receivers

The TV receiver costs modelling applies only to the first Ofcom scenario where there is investment made into the DTT network and as a result of the investment, there is a need to upgrade a proportion of consumer devices to support DVB-T2. In practice, the domestic TV set upgrade may occur before any DTT network upgrade, although we don't model this level of timing detail for this study.

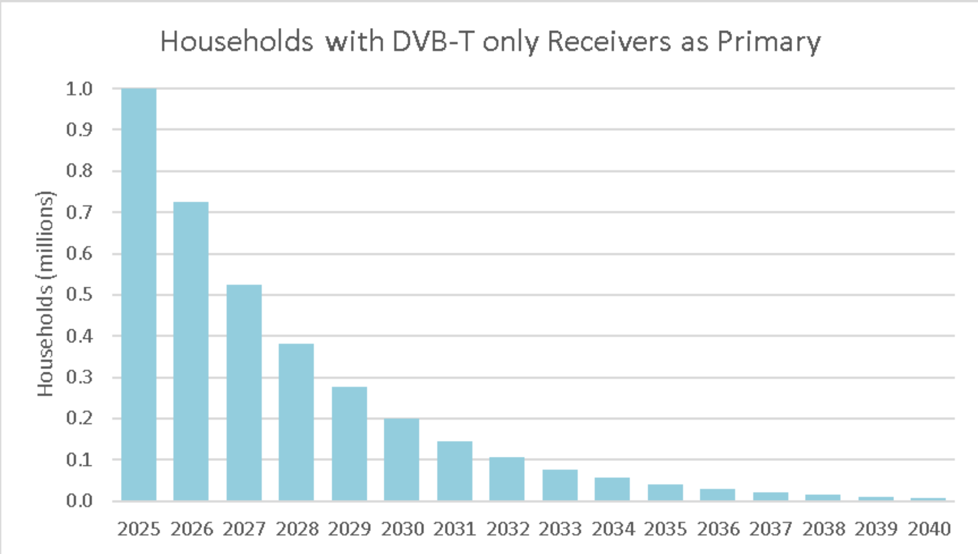
A key decision for this case and other cases where the DTT network receives an investment or upgrade to DVB-T2 is when to deploy DVB-T2 in the DTT network? The earlier the deployment of DVB-T2 into the DTT network will mean there are more DVB-T only receivers which will need to be upgraded to support DVB-T2. During our interviews with stakeholders, it was apparent that there is little hard evidence as to estimating the number of Households with DVB-T only TV receivers.

It was however reported by '3 Reasons' in the Ofcom Future of TV Distribution report [76]there may be around 0.2m DTT homes with a DVB-T receiver as their primary TV set and about 0.9m DTT homes with a DVB-T receiver as at least a second TV set. We estimate, as of 2025, there may be currently around 1m DTT homes with a DVB-T only receiver as their primary receiver. The exhibit below illustrates our assumed population of DVB-T only receivers (as the primary device) in the UK.

[75] https://www.fmamtv.com/products/TV/OMB%20Digital%20PL.html

[76] Ofcom - Future of TV Distribution Early market report to Government – May 2024

Exhibit 16: Assumed households with a DVB-T only receiver as the primary device



Source: Ofcom, 3 Reasons, and Coleago Consulting

We assume that any upgrades to TV receivers would be in the form of a low-cost DVB-T2 "Freeview" style set-top box device. Market prices today for set-top box devices are around £20-25. If there was to be some kind of subsidy programme to encourage users to migrate to DVB-T2 then a set-top box or voucher (which could be used for a new TV set) could be issued. We don't suggest who or where such subsidies might come from, but more of the cost in doing so. Again, any investment in the DTT network is likely to be a complex mix of stakeholders and future payment mechanisms, rather than any single simple transaction by one party.

Internationally, subsidies have also been provided for DTT upgrade programmes. In France vouchers worth €25 were issued for low-income households during their campaign to migrate households from MPEG2 to MPEG4 in 2016. In Czech Republic, Free set-top boxes were issued to pensioners and welfare recipients for their transition to DVB-T2/HEVC. In Italy between €50-€100 discounts were provided for low-income consumers to purchase new TV sets for the transition to DVB-T2/HEVC. An EC study forecast that the cost of replacing receivers with DVB-T2 (with MPEG4 coding) in the UK would be roughly €50 million[77] in 2022, assuming a seven-year natural replacement cycle. The same study found that a DVB-T2 receiver replacement to HEVC instead of MPEG4 would add an extra to 130% to replacement costs (on average across EU member states).

We conservatively **assume for simplicity that a £50 cost for all Households which have a DVB-T only TV receiver**. Strictly such a scheme should include means testing so financial support is given to those who need the support and as a result not all 200,000 households in 2030 would qualify, although it is expected a large proportion would qualify. Additionally, it might be pragmatic to issue set-top boxes which can support hybrid IPTV and DTT thereby maximising the opportunity later to transition to IPTV. Platforms such as Freely for hybrid DTT and IPTV are not offered in a set-top box at present. This may change in the future. However, for simplicity we assume £50 per household which would be either a set-top box supporting IPTV/DTT or a voucher for a TV set supporting at least DTT (as not all TV vendors support Freely at the moment). The £50 per household figure is assumed to also include costs associated with awareness campaigns, helplines and pre/post transition support programmes to help more vulnerable groups of society. We don't make any estimates as to the costs for such support programmes and this would be part of DMSL's remit to deliver as they have done for previous spectrum clearance activities. We also assume that conversion of any additional DVB-T only receivers in any household would not be part of a subsidy programme.

7.1.4 DTT network re-engineering costs for full IMT600 band clearance

Any DTT network re-engineering costs for accommodating 600 MHz clearance activity for an IMT600 band plan applies to Case 2 of the first Ofcom scenario where there is investment made into the DTT network, a reduction in Multiplexes, and a

[77] VVA & LS telcom for the EC, "Study on the use of the sub-700 MHz band (470-694 MHz)", 2022

decision for spectrum clearance is made for IMT600. These costs also apply to Cases 3 and 4 associated with the second Ofcom scenario where no investment is made in the DTT network, the DTT network is reduced to a core service, there is a reduction in Multiplexes, and a decision for spectrum clearance is made for IMT600.

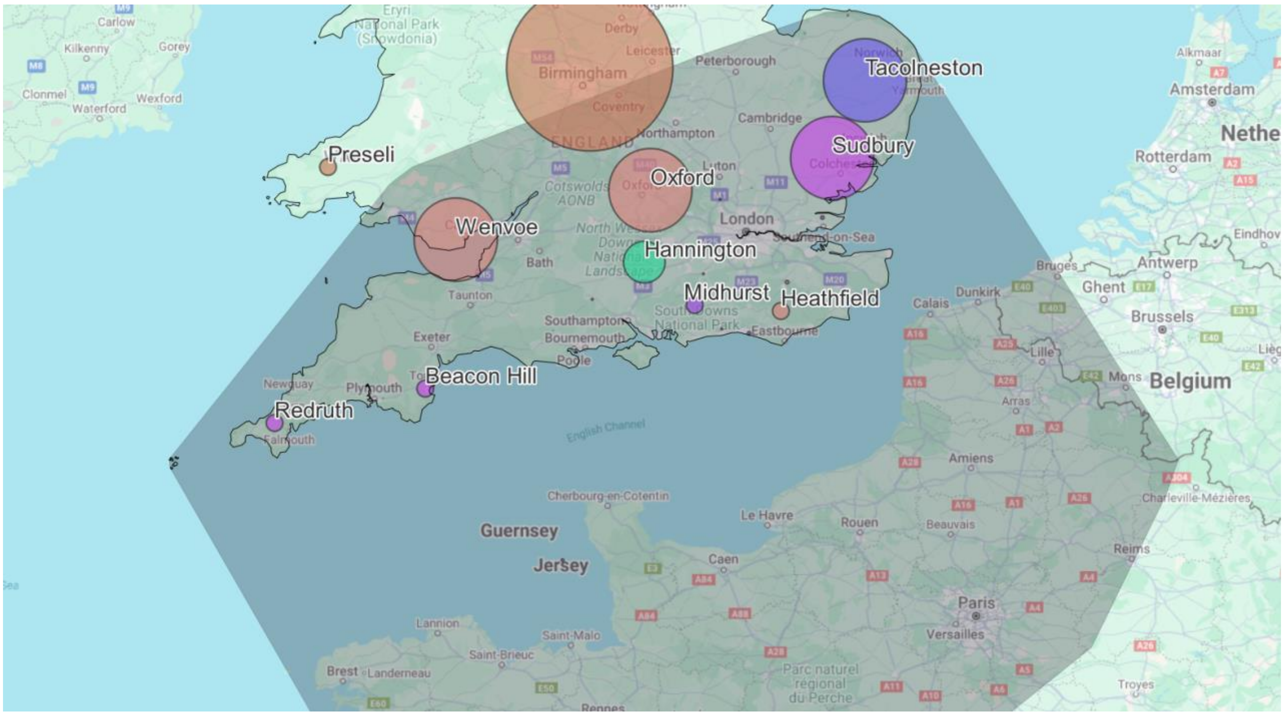
During the 800 MHz and 700 MHz spectrum clearance in the UK, these were done under a European collective and harmonised decision with a co-operative agreement that all administrations clear spectrum. A decision for spectrum clearance of 600 MHz could be less harmonised across Europe as we are seeing many countries investing in DTT networks for delivery of UHD content, notably France, Italy and Spain having made, or in the process of upgrading their DTT networks. Any investment of course would expect to provide service for several years, and which may go well beyond 2035. If France intends to maintain a DTT network beyond 2035 this may become a barrier for what the UK might want to achieve with the UHF spectrum. For example, if France wishes to run its DTT network with the full 470-694 MHz spectrum then why would France adjust its DTT frequency assignments to accommodate the UK's own interests? There is no obligation or agreement that France would have to coordinate with the UK in this regard.

In the worst-case situation, where the UK wanted to clear 600 MHz, but neighbouring countries did not want to clear 600 MHz then the UK would have to repack the DTT network into channels 21-37 with the constraint not to impact French, Irish, Dutch and Belgian DTT allotments. The Belgian DTT network only uses four UHF channels which are all above Channel 39 and there are reports that the remaining DTT sites will be closed down[78] The Irish DTT network only has two Multiplexes and given the similarities of the UK and Irish DTT networks, there may be some appetite that UK and Ireland could coordinate, but this is a subject for further debate and exploration.

To put this challenge into some context, the exhibit below shows all UK DTT sites which use channels 39-48 above 10kW ERP and fall within the UK-France coordination zone. There are up to nine sites which would require repacking into channels 21-37, and we'd expect several more sites requiring repacking because of these nine sites being assigned new frequency plans. This study would not be able to answer this question fully, and we recommend that this is in area of further study (if not already being looked at by stakeholder groups).

However, for the purposes of this study we shall assume that a UK DTT frequency plan using channels 21-37 could be found with minimal impact and/or minimal concessions for coordination with France, Ireland and the Netherlands.

Exhibit 17: DTT sites with Multiplex ERP>10kW, using UHF channels 39-48 and within the UK/France co-ord zone



Source: Ofcom, Arcep, and Coleago Consulting

[78] https://www.broadbandtvnews.com/2022/01/05/rtbf-wants-to-switch-off-fm-and-dvb-t

For the 700 MHz clearance a cost estimate was provided by Arqiva and published by Ofcom in Ofcom's 700 MHz decision. These cost estimates were around £400m, and the actual costs came in at £350m[79]

In Ofcom's 700 MHz decision document, the largest cost components were estimated to be the need to swap main broadcast antennas out since existing antennas at the time were narrowband only supporting the range of frequencies they needed to support. For example, if a DTT site was using UHF Channels within 51-60, but needed to be moved to say UHF Channels 31-37 for 700 MHz clearance then the entire broadcast antenna system needed to be replaced. This was an enormous engineering task as can be appreciated. In addition to these civil engineering costs, there was a need to deploy temporary masts to ensure continuous DTT service and resilience. One of the innovations which came from Arqiva was the design and deployment of a wideband broadcast antenna which could allow pre and post clearance frequencies to be accommodated[80]. For this study we have assumed that all DTT antenna systems upgraded during the 700 MHz clearance would be able to support the full UHF 21-37 channel range, and antennas which historically were always using lower UHF channel groups were unaffected (such as Crystal Palace). We therefore expect that there would a much smaller demand for antenna systems to be modified for a 600 MHz clearance, although antenna systems for the above example nine sites within the France-UK coordination zone (and those which fall in the UK-Ireland coordination zone) may need radiation pattern modifications in the Azimuth and Elevation planes to ensure neighbouring country frequency allotments are protected.

In our analysis of future spectrum evolution cases, we propose for Cases 2 and 3 that the number of DTT Multiplexes reduce from six to three, and in Case 4 we propose the number of Multiplexes drop from six to two. It is common at many main broadcast sites to have two sets of antenna systems, one main antenna system and one fall-back antenna systems for resilience measures in case of antenna system failure or maintenance. The use of these antenna systems may facilitate pre and post switchover and require less of a need to use temporary masts for any 600 MHz clearance work. As stated earlier, we were unable to interview Arqiva who would be the experts in advising on DTT network costs associated with any 600 MHz clearance effort. We recommend that this is an area for further study to refine on our study.

Whilst costs for re-engineering the UK DTT network for 700 MHz clearance were around £350M, the costs for 700 MHz clearance in many other countries vary significantly. Different countries of course have different quantities of DTT sites and types, different numbers of Multiplexes, different populations, different licencing term, and different bases for calculating costs or compensation. These costs are referenced in a report published by EU4 Digital[81]. As a benchmark it is worth noting that in Germany, the authorities provided EUR50m as reimbursement. In France, a compensation fund was implemented of around EUR67m. In Italy, national broadcasters were compensated with EUR304m and local broadcasters with EUR276m.

Any 600 MHz clearance effort should require much less civil engineering and DTT site antenna swap-outs (than for the 700 MHz clearance), since broadband antennas are in place in most DTT sites which were re-engineered during the 700 MHz clearance. It will be these sites again which would be expected to be re-planned again since DTT sites using lower groups of UHF channels would generally be less affected with a 600 MHz clearance such as Crystal Palace for example. However, without engaging in a full DTT re-planning exercise it is difficult to estimate these costs as there may be a need to implement different DTT antenna patterns in Azimuth and Elevation to arrive at a re-packed DTT network plan for meeting any new coordination and bi-lateral agreements. We are unclear whether existing antennas at DTT sites can have their antenna patterns adjusted in-situ through implementing different phase and combining configurations, or antenna systems would require complete replacement. This is something we were unable to verify.

As a qualitative statement **we make a broad statement that that a nominal conservative cost of around £200m** in 2035 might be the price tag for 600 MHz clearance. This figure is around 1/3 of the actual costs of 700 MHz in real terms accounting for inflation. This £200m figure also includes consumer information schemes, consumer aerial replacements, and PMSE equipment upgrades/replacements, as they were for the 700 MHz clearance costs.

In the 700 MHz clearance efforts domestic aerial replacements was estimated at £3m-£6m. We don't have any references as to what this cost. However, domestic aerial swap outs during the 700 MHz clearance work may have already swapped aerials from Group C/D to Group B or ideally wideband Group K. Any Group B aerials which remain and are toward the edge of DTT service areas would need replacing for Group A aerials. A more detailed study would be needed to quantify the costs. However, for the purposes of this study, we assume a nominal £5m costs as of 2035. Aerial upgrades could be

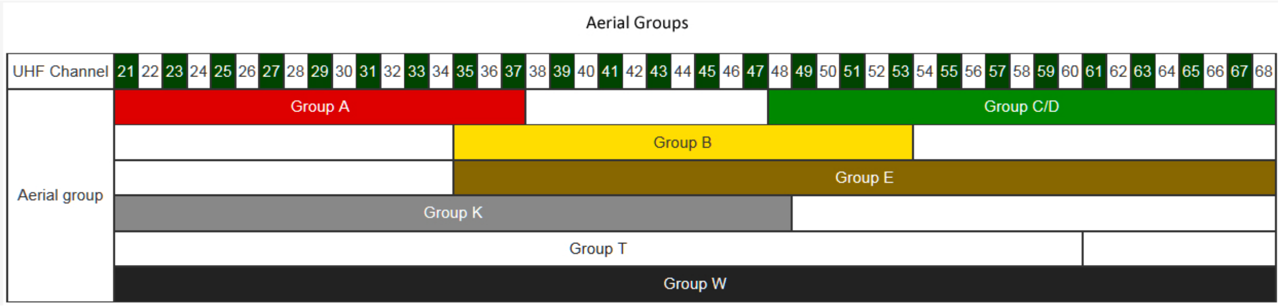
[79] https://www.gov.uk/government/news/big-step-forward-in-digital-infrastructure-revolution-brings-benefits-of-5g-closer

[80] https://www.arqiva.com/news-views/views/finding-an-innovative-solution-to-help-clear-the-700 MHz-band-the-broadband-antenna

[81] https://eufordigital.eu/wp-content/uploads/2020/11/EU-best-practice-report-on-releasing-and-reassignment-of-the-700-MHz-band.pdf

part of DMSL's remit for example rather than issuance of vouchers as most households would be unaware of the aerial type they may have. How this is aerial upgrade is delivered is not important for this study.

Exhibit 18: Domestic TV Aerial groups



Source: Ofcom

PMSE impact and any compensation would need to be better understood, and an area for further study. If hypothetically WMAS does indeed effectively double spectral efficiency or channel capacities, then having say 10x WMAS base stations each supporting an 8 MHz channel might satisfy the needs of a large Theatre, TV/film production studio, or large music festival which otherwise might have been significantly impacted by a 600 MHz clearance. If such a WMAS system might cost £0.5m, and there are 40 locations across the UK which demonstrate a need for such UHF PMSE demand then this amounts to £20m as of 2035. These figures are purely examples and not to be taken literally as such pricing of WMAS is not publicly available, but for the purposes of this study we assume £20m as an estimation aimed at the PMSE industry. As a benchmark, Ofcom had estimated between £13m and £20m for PMSE compensation for the 700 MHz clearance.

7.2 DTT Capacity modelling

7.2.1 Existing DTT network

The current DTT network is comprised of six Multiplexes. There are three Multiplexes dedicated to PSB, and three Multiplexes dedicated to Commercial or non-PSB broadcasters. The three PSB Multiplexes each serve substantially the same geographic areas serving around 98.5% of the UK population based on traditional rooftop aerial reception mode. The three non-PSB Multiplexes serve around 90% of the UK population, although some stakeholders consider the actual coverage to be a little higher than 90%. All Multiplexes are delivered through the 80 Main Broadcast DTT sites where transmitters equipment for each of the Multiplexes are co-located. The PSB Multiplexes are also re-broadcast from over 1,000 low-power relay sites across the UK which provide coverage extension and coverage gap filling in areas where the main broadcast stations are not able to serve. The non-PSB Multiplexes are in general not delivered via the relay sites.

The first two Multiplexes operated by BBC and D3&4 use DVB-T transmission along with MPEG2 video encoding for supporting several TV channels, Radio channels, and data channels which are statistically multiplexed onto each Multiplexer. The first two Multiplexers have an inherent capacity of around 24Mbps which relate to a set of modulation, channel coding and Guard Interval parameters from the DVB-T Specifications. The BBC operate what is termed MUX-1 or sometimes called PSB-1 and deliver around eight Standard Definition TV channels with 720 x 576 resolution (which we refer to as SD1). The choice of TV channel mix is important for optimising channel capacity and visual quality requirements. The BBC sometimes operate more than eight TV channels in certain regions, and they carry Radio and data too. Similarly, MUX-2 (sometimes called PSB-2) carries the TV channels for ITV, C4 and C5 with the same 720x576 Standard Definition resolution. Whilst MUX-2 appears to carry more TV channels than MUX-1 it does not carry Radio and carries less data payload than MUX-1. Additionally, the choice of TV channel content mix, statistical multiplexer and quality threshold requirements can be different between Multiplex operators. This serves as a useful example of why it is often difficult to prescribe a simple formula to assign a data rate to a TV channel. It all depends.

Exhibit 19: Current Multiplex configurations with approximate TV channel counts

2025	MUX-1 BBC A	MUX-2 D3&4	MUX-B BBC B	MUX-A SDN	MUX-C ARQ1	MUX-D ARQ2
	DVB-T	DVB-T	DVB-T2	DVB-T	DVB-T	DVB-T
MUX capacity	24 Mbps	24 Mbps	40 Mbps	27 Mbps	27 Mbps	27 Mbps
Typ. #Chs	8 x SD1	14 x SD1	3 x SD2 9 x HD	16 x SD2	16 x SD2	16 x SD2
Pop Coverage	98.5%	98.5%	98.5%	90%	90%	90%

Source: Digitalbirate.com, Ofcom and Coleago Consulting

The third PSB Multiplex, MUX-B (sometimes called PSB-3) is operated by the BBC. This Multiplex uses DVB-T2 and has TV channels encoded using MPEG4/AVC. The payload capacity is around 40Mbps and carries around nine High Definition (1920x1080 resolution) and three lower Standard Definition (544 x 576 resolution) TV channels. The lower Standard Definition of 544 x 576 we refer to as SD2. The 40Mbps capacity has a similar Signal to Noise Ratio (SNR) requirement to DVB-T operating at 24Mbps. As such all PSB Multiplexes have about the same coverage footprint from a DTT site.

The three non-PSB Multiplexes use DVB-T and operate at around 27Mbps capacity, which has a higher Signal to Noise requirement than MUX-1 and MUX-2 which mean they will serve a smaller area than the PSB Multiplexes when transmitting from the same DTT site. These three Multiplexes carrying between 15-18 TV channels at the lower Standard Definition resolution of 544 x 576. SDN operate MUX-A and Arqiva operate both MUX-C and MUX-D.

7.2.2 Future DTT network options

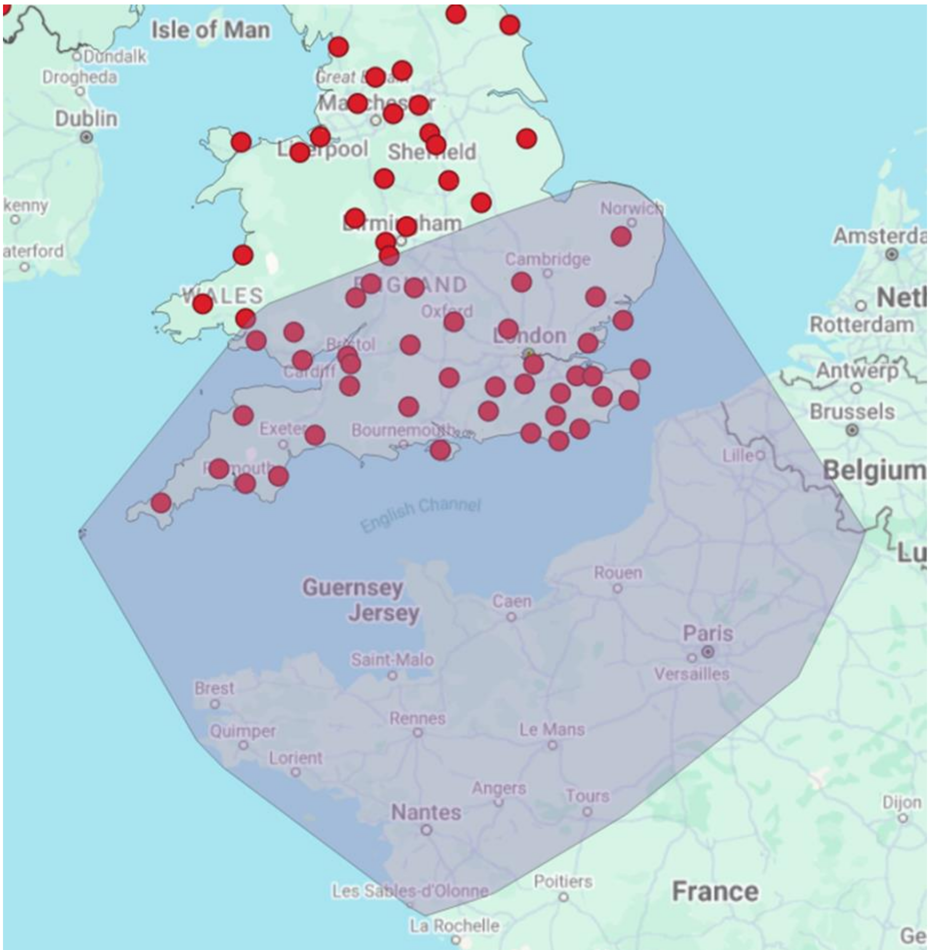
The DVB-T2 specifications from ETSI under EN 302 755 can be configured to provide several different capacities, using different modulation and channel coding schemes. However, the Digital Television Group (DTG) test TV receivers intended for sale in the UK market, to a reduced subset of all possible configurations. The DTG D-Book specifies only five configurations or modes, of which only the 40Mbps variant is feasible for deployment. We therefore do not consider the design freedom where different DVB-T2 configurations are used.

7.2.3 SFN considerations

We do not consider any cases using Multiplexes with a Single Frequency Network (SFN) topology. All stakeholders interviewed during our study regarding this topic strongly advised against considering an SFN. Whilst on a clean sheet of paper approach an SFN can show spectral efficiency gains over a more traditional Multi Frequency Network, the practical realities of deploying an SFN are not feasible.

Our own research and views expressed by several interviewees stressed that an SFN would require tremendous coordination effort with neighbouring countries to carve out a common single frequency which could be used across the UK. If the UK sought a common UHF channel for an SFN then that channel could not be used anywhere in the coordination zone in Northern France, Eastern Ireland, and The Netherlands. This in turn means those countries would have fewer UHF channels with which to design their own DTT network thus restricting capacity. Even, if a neighbouring country such as France wanted to carve out its own SFN, then the UK would have to remove the UHF channel France wishes to use for its SFN in the coordination zone in Southern England and thus have fewer channels for use. The extent of the international coordination zone between the UK and France is shown below for reference.

Exhibit 20: UK-France DTT coordination zone and UK DTT site locations requiring coordination



Source: Ofcom, Arcep and Coleago Consulting

Furthermore, an SFN means regional content such as news and commercial advertising is not possible. This may not be critical for the non-PSB Multiplexes, however. Additional barriers for an SFN deployment in the UK include the fact that all UK TV receivers are tested by the DTG against a sub-set of DVB-T and DVB-T2 transmission modes. There is only one mode for SFN which was designed for small regional SFNs. This mode is for DVB-T2 with a Guard Interval of 1/16 which means any DTT service received from overlapping transmitter service areas where the distance difference is greater than 17km means there is risk of interference and loss of service. If a DVB-T2 mode with a longer Guard Interval is used, then the DTG would need to start testing all previously tested TV Receivers for compatibility, and any receivers found not to be compatible would require upgrading or replacing. A larger Guard Interval consumes capacity, with the largest Guard Interval of 19/128 on DVB-T2 reducing Multiplex capacity to about 87%. Finally, even with a large Guard Interval, an SFN needs a higher density of overlapping sites to reduce the probability of interference. Such higher densities are found in DTT networks in The Netherlands and Germany using Medium-Power/Medium-Tower deployments, designed for indoor TV receiver coverage, where DTT site deployments are typically no more than 20KW in ERP power and Tower heights are typically less than 100m. The UK DTT network however has been built with a High-Power/High-Tower topology serving rooftop aerials with up to 200kW ERPs and towers above 200m.

7.2.4 Video coding channel rates

As highlighted in the previous section, it is not straightforward to assign a simple relationship for TV Channel data rate with a particular video encoding scheme. Encoding with MPEG4/AVC can in theory support up to two times the number of channels as MPEG2. However, we assume the Channel Rates under MPEG2 and MPEG4/AVC coding in the following table for the purposes of this study. These data rates have been derived from our analysis of real live UK broadcast streams reported via Digitalbitrate[82] and therefore aim to reflect a UK context for channel capacity, rather than a theoretical discussion. It is worth noting that DTT in other countries can have widely different channel rates for the same SD or HD service in the UK. For example, TV channels using the 720x576 SD1 resolution on the Italian 'Cairo Due' Multiplex reserves only 0.4Mbps using MPEG4/AVC coding and statistically multiplexes over 40 channels. Clearly this SD1 resolution would be received at a lower quality than say the BBC who we would assume to need 1.4Mbps using MPEG4/AVC being equivalent to 2.2Mbps using MPEG2.

Exhibit 21: Assumed Statistically Multiplexed TV Channel bit rates for different video coding

Stat MUX Ch Rates	MPEG2	MPEG4	HEVC
UHD (3840x1920)	-	15Mbps	10Mbps
HD (1920x1080)	-	4.0Mbps	3.0Mbps
SD1 (720x576)	2.2/1.5Mbps	1.4/1.0 Mbps	1.0/0.7Mbps
SD2 (544x576)	1.3Mbps	0.8Mbps	0.5Mbps

Source: Digitalbitrate.com and Coleago Consulting

These data rates serve to provide a simple way of comparing different cases of the DTT network using a reduced set of Multiplexes against today's TV channel mix and quantities.

During our interviews it was clear that there is little or no appetite for supporting UHD content via the DTT platform for the UK market. Some stakeholder held the view if there was a desire for consumption of UHD then this is best delivered via IPTV. Given this stance and that UHD content has been implemented using HEVC video coding to date, we have not studied any cases where there is an investment in the DTT network for DVB-T2 and HEVC coding.

7.2.5 Local TV Multiplexes

In our analysis of the various DTT and spectrum evolution cases we have assumed that the local TV Multiplex licence (Comux) will continue and is unaffected. Some local TV services which are licenced separately have ceased in recent times such as Nottingham's local TV service[83], although many local TV service licences were also renewed recently[84]. This Local TV Multiplex broadcasts at much lower powers than the main PSB and Commercial Multiplexes, and as such can be generally frequency planned with more freedoms. If transmitters for the Local TV Multiplex are removed from sites, then this would mean PMSE would have access to more spectrum on average.

7.3 PMSE capacity considerations

If DTT was reduced from six to three Multiplexes as considered in this study, and a 2 x 35 MHz IMT600 band plan adopted, this will reduce the available PMSE spectrum to around 106 MHz. This is illustrated in the following exhibit where we have assumed that all PMSE services would end up below 606 MHz on the assumption that PMSE requires at least 4 MHz from IMT600 band edges, and as a conservative stance we assume the 10 MHz duplex gap of the IMT600 band plan becomes unusable. It may however be possible that IMT600 can employ additional Out of Band (OOB) emission filtering at the base station which exceed 3GPP specifications, which can reduce interference risk to PMSE channels in the duplex gap. The cost of developing bespoke filtering across thousands of base stations may be prohibitive, especially if this may only free up a few MHz of PMSE spectrum. Reduction of OOB emissions from devices beyond what 3GPP specifications provide would not be feasible.

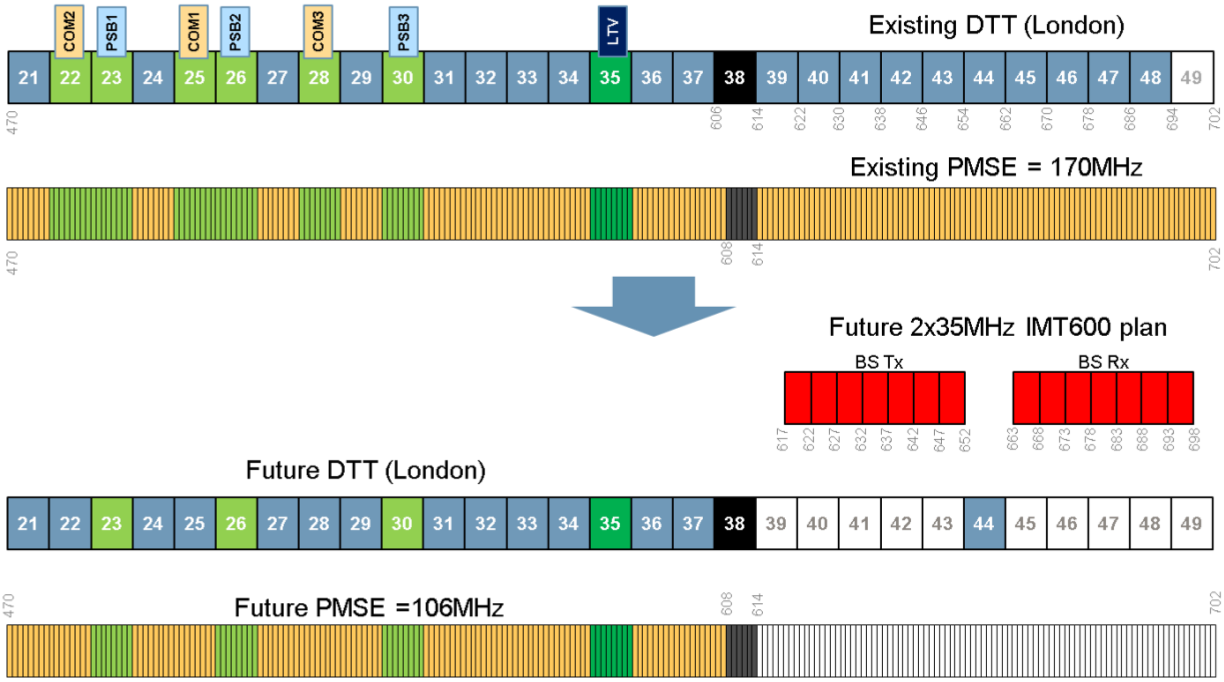
[82] https://www.digitalbitrate.com/dtv.php?lang=en&liste=2&live=35

[83] https://rxtvinfo.com/2025/whats-the-future-for-freeview-local-tv/

[84] https://rxtvinfo.com/2025/local-tv-operator-thats-tv-confirms-freeview-channel-renewal-bid/

The example below is for London, where we see most PMSE demand. We assume that the Local TV Multiplex continues in one form or another or could equally represent a UHF channel with 5G Broadcast deployed in the future but with no Local TV Multiplex.

Exhibit 22: UHF spectrum between DTT, PMSE and 2 x 35 MHz IMT for London assuming DTT reduces to 3xMUX

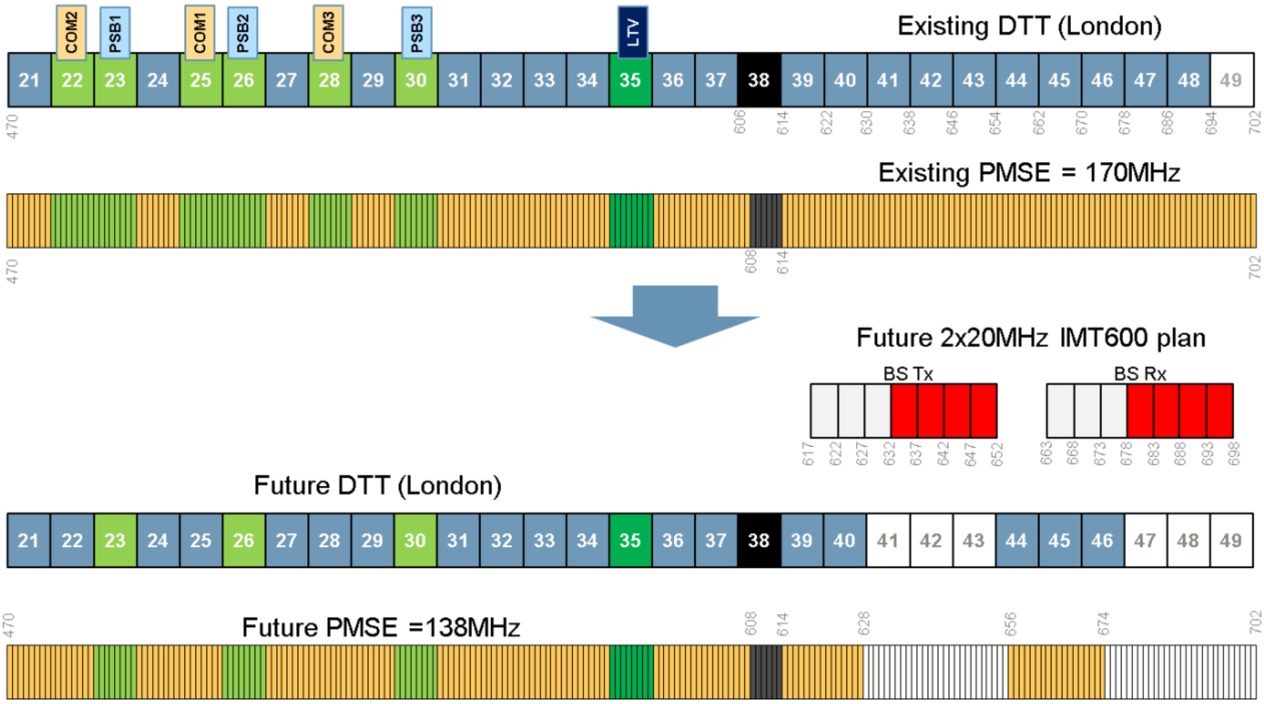


Source: Ofcom and Coleago Consulting

There are however areas in the UK which are served by two main DTT broadcast stations which can mean even less PMSE spectrum is available since another six UHF channels would become unavailable, although there wouldn't likely be a Local TV Multiplex channel being used in the areas served by two DTT main broadcast stations. Examples of such areas include York which is served by both Emley Moor and Bilsdale DTT areas, and areas around Bristol served by the Mendip and Wenvoe DTT transmitters. Our analysis of the PMSE licence data suggests that these areas don't tend to correlate strongly with PMSE demand. As such, we don't consider these areas in our analysis, although we acknowledge that some areas of the country may less opportunity to host events which demand high-capacity PMSE, such as a Eurovision event or even a choice of a TV/film production.

If DTT was reduced from six to three Multiplexes, and a 2 x 20 MHz partial IMT600 band plan was adopted, this will reduce the available PMSE spectrum to around 138 MHz. We study this outcome in a number of spectrum cases in this section as this 2 x 20 MHz plan may be possible without significant coordination effort or re-engineering of the DTT network. This 2 x 20 MHz IMT600 plan is illustrated in the following exhibit where we have assumed that all PMSE services would require at least 4 MHz spectral distance from the band edges of IMT600 downlink and uplink sub-bands.

Exhibit 23: UHF spectrum between DTT, PMSE and 2 x 20 MHz IMT for London assuming DTT reduces to 3xMUX



Source: Ofcom and Coleago Consulting

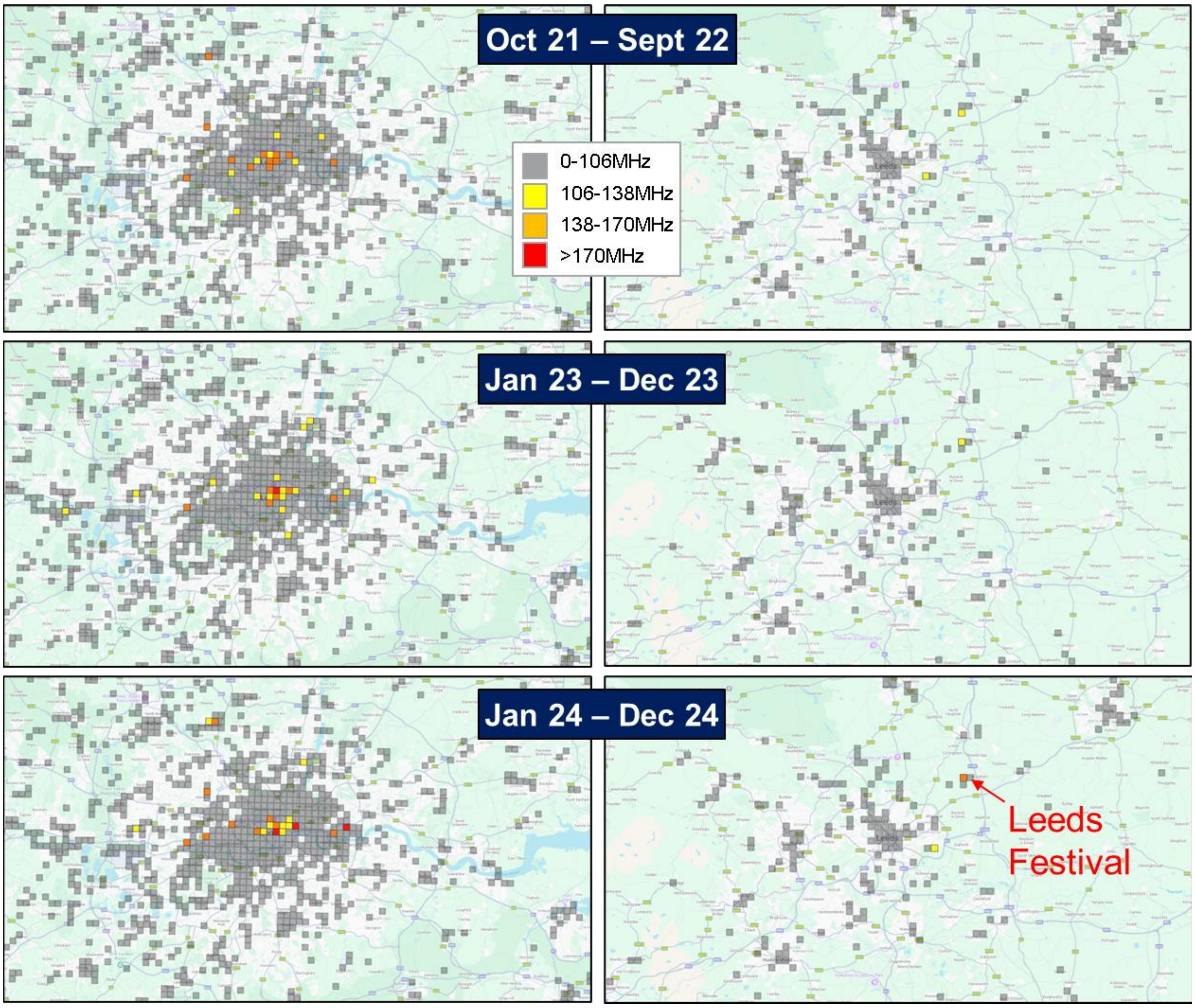
Our analysis of the Ofcom PMSE licence data over the three 12-month periods indicated that around 34 locations across the UK in any one year which had long-term PMSE spectrum demand of greater than 106 MHz in the interleaved DTT spectrum. Long-term or persistent PMSE users were those with licences for over 30-days at any time over any 12-month period. Additionally, there were no more than 14 locations across the UK which had temporary (having licences for less than 30 days) PMSE spectrum demand of greater than 106 MHz at any time over any of the three 12-month periods.

These locations are illustrated in the exhibit below. For the temporary PMSE licences where many popular music festival locations can be seen including Glastonbury, Leeds and Reading festivals, and Kendal Calling. The longer term PMSE licence locations are centred on production studios in major cities and London's West End theatres.

7.3.1 Geographic and time sharing between PMSE and IMT600 spectrum

The exhibit below illustrates the spatial distribution of peak demand within a 12-month period of PMSE licences for three 12-month periods in in two urban areas: London and West Yorkshire. All squares are 1km x 1km and all grey squares are where there were PMSE licences, but peak PMSE demand was less than 106 MHz in any of the three 12-month periods analysed. Central London and in particular the West End reveals persistent demand for PMSE as expected. The area shown for West Yorkshire covers around 2.5 million people yet shows that demand for PMSE spectrum above 106 MHz occurred only five times within the three 12-month periods. This was for Leeds Festival, a 3-day music festival in August, and a 1-day music festival called Slam-Dunk North.

Exhibit 24: Locations in London and West Yorkshire of peak PMSE spectrum occupancy over three 12-month periods



Source: Ofcom and Coleago

The table below summarises the number of 1km² locations for each of the 12-month periods analysed where PMSE licence demand was (1) above 170 MHz, (2) above 138 MHz, and (two) above 106 MHz. If the number of 1km² locations using more than 170 MHz represents the current limit for PMSE spectrum supply, then locations with more than 106 MHz would represent the limit for PMSE spectrum supply in the event a 2 x 35 MHz IMT600 allocation was made in the UHF band, and the DTT national network was reduced from Six to Three Multiplexes, and one local TV Multiplex was maintained for high-population areas. Locations with more than 138 MHz would represent the limit for PMSE spectrum supply in the event a 2x20 MHz or partial IMT600 allocation was made in the UHF band, and the DTT national network was reduced from Six to Three Multiplexes, and one local TV Multiplex was maintained for high-population areas.

Exhibit 25: Number of 1km² locations exceeding 170 MHz, 138 MHz and 106 MHz of PMSE spectrum demand

# of 1km² Locations	Oct 2021 – Sept 2022		Jan 2023 – Dec 2023		Jan 2024 – Dec 2024	
	<30 days	>30 days	<30 days	>30 days	<30 days	>30 days
>170 MHz	1	0	2	1	4	1
>138 MHz	11	5	9	5	17	6
>106 MHz	22	14	28	14	34	11

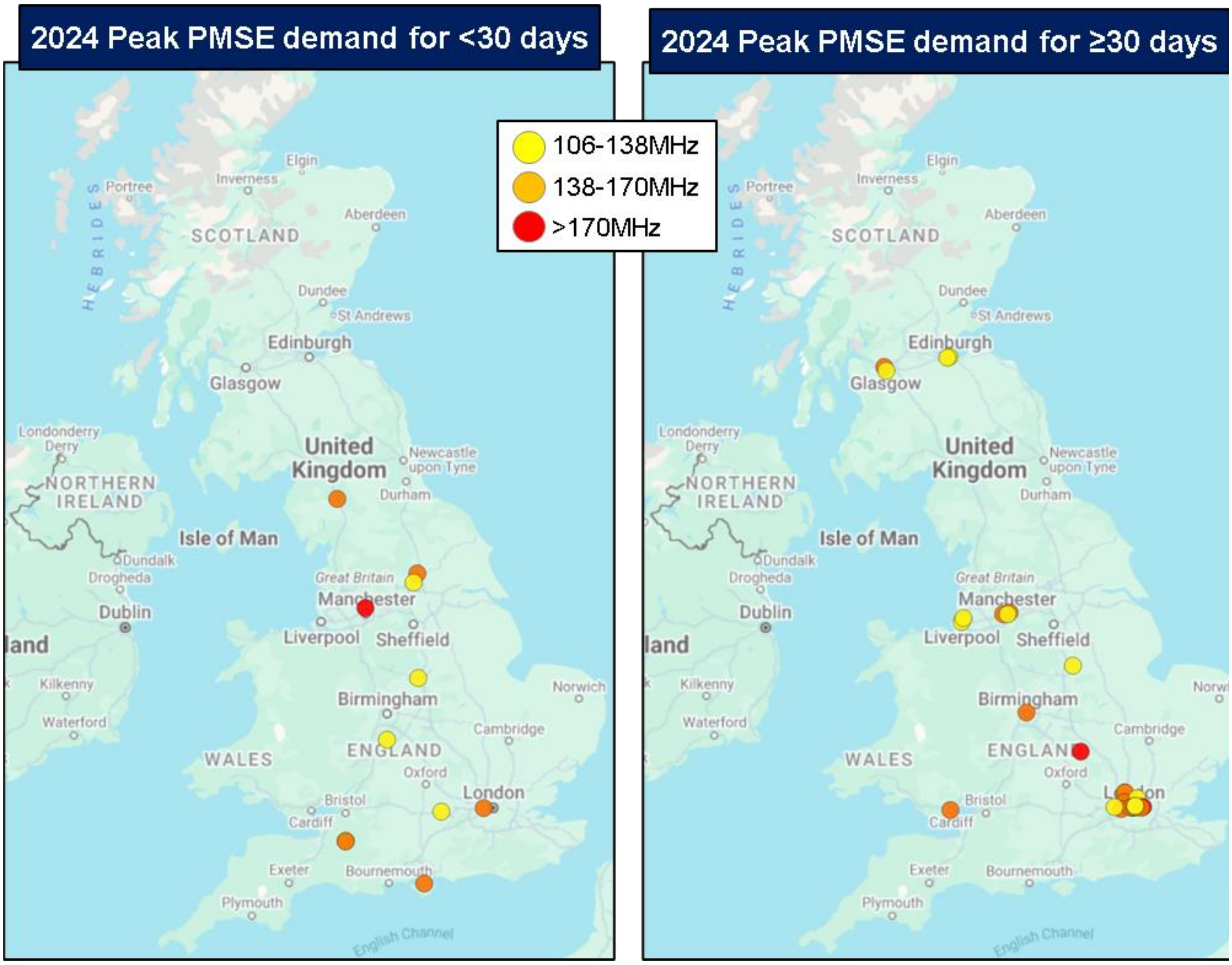
Source: Ofcom and Coleago

The idea of sharing spectrum between PMSE and IMT600 on a geographic and/or time-sharing basis has been discussed previously as one mechanism by which PMSE could have access to an optimum quantity of spectrum when and where it is needed whilst causing minimal impact to the IMT600 network.

Given that almost all the high PMSE demand events with <30-day licences are music festivals, the idea is that these events are known and planned for. If a mobile operator can turn off any IMT600 base stations in and around these areas for the handful of days, the music festival is running then PMSE would in fact have access to an additional 24 MHz of spectrum if the DTT network moves to three Multiplexes. Mobile operators would not rely on using 600 MHz for festivals and instead always use higher bands above 1 GHz with higher-order sectorisation from temporary masts to maximise capacity as coverage of a festival site does not need sub-1-GHz spectrum.

Additionally, the longer terms PMSE licences with demand above 106 MHz are all in major cities, apart from Silverstone. Many of these locations may use PMSE indoors and are known locations. Appropriate geo-graphic coordination might allow PMSE to have access to an additional 24 MHz. A spectrum sharing framework, spectrum management approach, appropriate licence conditions and possible priority status for protection of PMSE (as a grandfathered right of the spectrum) would all need to be considered, consulted and agreed upon.

Exhibit 26: Location exceeding 106 MHz of PMSE Spectrum demand during 2024 by licence duration



Source: Ofcom and Coleago

The locations are shown as a circle with radius of 10km. However, the distances for protection of PMSE from IMT600 could be a subject of recommended further study and debate beyond this report. PMSE used indoors for example in production studios or theatres in urban areas might need shorter coordination distances, whereas outdoor music festivals in rural areas may need longer coordination distances.

7.3.2 Planning PMSE events with more intensive spectral re-use

The PMSE industry has been generally working much harder in recent years to make finite spectrum for PMSE work at large events. This involves re-using PMSE channels at events on different stages and at different times on the same stage.

Some of Ofcom's PMSE planning activities has indicated that at festival events such as Glastonbury, there may be further opportunity to increase spatial and temporal frequency re-use. This would entail planning of PMSE frequencies even more intensively by reusing frequencies across more stages and across more timeslots. Also, it is understood that historically there can redundancy built into PMSE event planning such as having large PMSE band allocations on top of stage setups. Reducing redundancy might help to provide some additional relief, albeit at an increase in calculated risk.

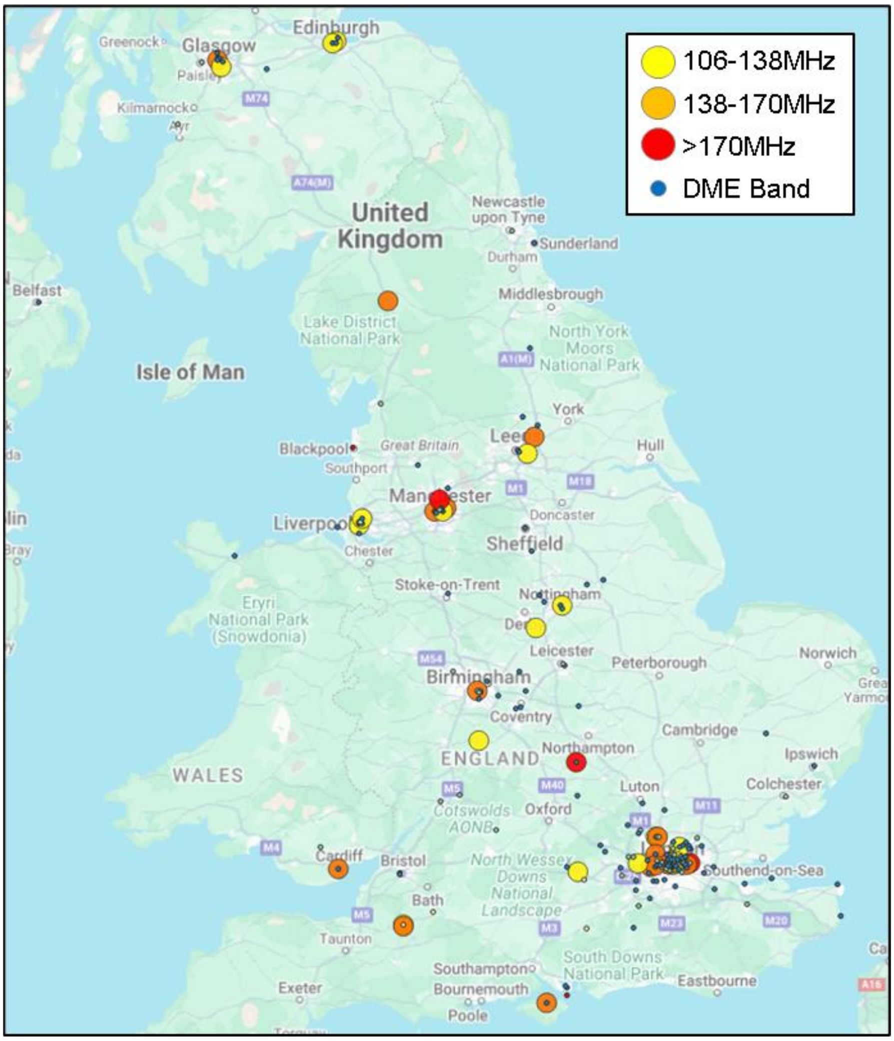
Technologies such as WMAS also aim to provide improved spectrum management, device management across different device types which may lend itself to better exploiting shorter duration PMSE licences. The fundamental reduction in SNR requirements because of the WMAS wideband (8 MHz) channels should also facilitate more intensive spatial reuse of spectrum at these kinds of PMSE events. If WMAS can also alleviate the practice of adding redundancy, then this will help further. As a general statement, many of these promises of WMAS are hopeful but are yet to be fully tested, and we'll need to monitor PMSE usage over the coming years. There are also views from some that introduction of WMAS may foster further creativity and use of PMSE and as such WMAS allows more to be delivered in creative content rather than allowing the same creative content from less PMSE spectrum.

7.3.3 960-1154 MHz Aeronautical DME band for PMSE

As discussed in the key trends section of this report, the DME band for PMSE has emerged as a success in providing some meaningful PMSE capacity relief in lieu of the 700 MHz clearance. Analysis of 2024 PMSE DME licences revealed that there was generally a high correlation of PMSE demand with UHF and DME. However, there were many areas where there was high UHF PMSE demand, yet no DME PMSE demand which might suggest that PMSE was met by UHF, but it also indicates that those locations which did not use DME PMSE could potentially reduce their UHF PMSE demand.

The map below shows the 45 locations where UHF PMSE demand was 106 MHz or greater during 2024. Overlaid are the DME PMSE locations for 2024 too. There were 11 locations where DME is not concentric with UHF locations. These are areas where DME is not used alongside PMSE and include many popular music events such as Kendal Calling, Leeds Festival, Reading Festival, Camper Calling, Slam Dunk Festival, and Castle Donnington which could have in principle reduced UHF PMSE demand by at least 20 MHz (what we saw in the DME data as being generally available in DME) to 50 MHz (what we saw in the DME licence data as the upper availability). This evidence therefore shows promise that UHF PMSE demand could be alleviated in using DME PMSE.

Exhibit 27: 2024 UHF PMSE locations exceeding 106 MHz spectrum demand and DME PMSE locations



Source: Coleago Consulting and Ofcom

7.3.4 Potential for use of 733-758 MHz for high demand PMSE relief

The range 733-758 MHz falls within the duplex gap of the 700 MHz FDD mobile spectrum band. The range 738-758 MHz is currently licenced to BT/EE and forms what would be 3GPP Band 67 for Supplemental Downlink (SDL) services. The range 733-738 MHz is a guard band between Band 28/700 MHz Uplink and Band67/700 MHz SDL. The Band 67 spectrum has only been assigned in the UK, Denmark, Latvia and Slovenia to date. Other administrations have assigned part of this frequency range to PPDR, and others have not assigned the range to IMT services. The band has also been a subject of debate in industry consultations from national regulators considering spectrum roadmaps and auctions. Our research suggested that there are no modern smartphone devices currently supporting Band 67.

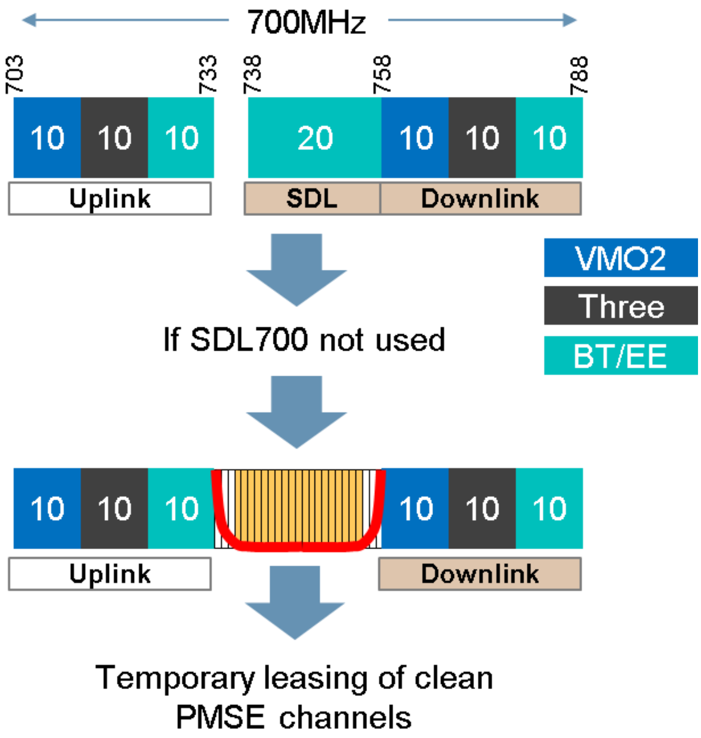
If there is no adoption of the band for several years (or at all) by the mobile industry, then could there be a possibility that the spectrum be utilised for PMSE, perhaps for the handful of high-demand locations and/or occasions? In the USA, there have been occasions where there has not been sufficient PMSE spectrum available at major events. In these situations, Special Temporary Authorizations (STAs) have been issued to PMSE often just for a few hours which allows PMSE users to access to spectrum which is not normally permitted for PMSE. An example of using of STAs was at Superbowl 2023[85]. In the US, T-Mobile and Dish Networks operate networks using 600 MHz and 700 MHz spectrum. If their licensed spectrum is

[85] https://newsroom.sennheiser.com/sennheiser-digital-6000-wireless-system-shines-bright-during-rihannas-super-bowl-lvii-halftime-performance-s8jthe

not in use in a location, an STA can be issued by the FCC. This was seen as one mechanism to provide relief to PMSE in the USA given that the PMSE industry has lost access to 600 MHz. Whilst this solution has worked it comes with uncertainty since it wouldn't be known if and where T-Mobile and Dish have deployed spectrum and relies upon requests made to the FCC.

Within the 733-758 MHz range there could be up 20 MHz of useful PMSE spectrum, taking into account the need to be a at least couple of MHz away from 700 MHz FDD band edges. Before the 700 MHz clearance this range of spectrum was in use by PMSE, and there may be PMSE equipment capable of tuning to this range still available, although we did not enquire.

Exhibit 28: Temporary leasing unused SDL700 spectrum for high-demand PMSE events



Source: Coleago Consulting

The spectrum in this range owned by BT/EE is currently not leasable so this would require some alteration to spectrum user rights and commercial leasing arrangement put in place between BT/EE and PMSE users. We believe the idea of such leasing rather than STA approach could be explored as an item for further study, assuming BT/EE might be open for exploration of course, as there is no obligation on BT/EE for exploring such an idea. Any further study might include RF measurements in the 700 MHz duplex gap to understand appropriate spectral distance from FDD band edges, leasing arrangements, licence conditions, and spectrum management approaches.

7.4 5G Broadcast

In our analysis we have not included or considered 5G Broadcast as a service which will compete in a meaningful way for access to the UHF spectrum over the next decade. Most stakeholders who expressed a view felt that 5G Broadcast is unlikely to become a regional, or national coverage layer for delivery of TV content to mobile devices. However, stakeholders did share views that 5G Broadcast may provide a useful broadcast content delivery method at sporting events, festivals, and other large events.

5G Broadcast is gaining some momentum elsewhere in Europe with large scale deployments planned, and chipsets can be enabled as demonstrated last year using a modification to Qualcomm powered Xiaomi devices to showcase 5G Broadcast at the 2024 Paris Olympics. If 5G Broadcast was deployed at sporting events or festivals, then it may occupy one UHF channel using a low power transmitter and hence used in interleaved spectrum. This would mean that the design of the DTT network would not be impacted, and not need any onerous international coordination effort, if at all. However, if 5G

Broadcast was deployed in this manner at such events then there would be be 8 MHz of PMSE spectrum available, and often in a location which needs PMSE spectrum.

If 5G Broadcast ever became a national or much wider network, it would need to be deployed on 1,000s of sites to meet the link budget for delivery to handheld devices. Tower Companies such as Vantage Towers in Europe are using their assets for deployment of 5G Broadcast technology across several countries[86]. Although unlikely as stated above, if a national 5G Broadcast network was deployed in the UK then this could be planned using single frequency network or multiple frequencies using interleaved DTT spectrum without impacting existing coordination agreements too much. A large scale 5G Broadcast network would however dimmish PMSE spectrum availability by 8 MHz if one UHF channel is deployed or 16 MHz if two UHF channels are deployed.

7.5 Ofcom Scenario 1 - Invest in more efficient DTT service

7.5.1 Case 1: Invest for six DVB-T2/MPEG4 Multiplexes

This case primarily serves as a reference case for other cases, rather than necessarily a probable case for the UK. In this case all current Multiplex licences run until end of 2034 and the BBC renew their MUX-B licence in 2026 until the end of 2034 also.

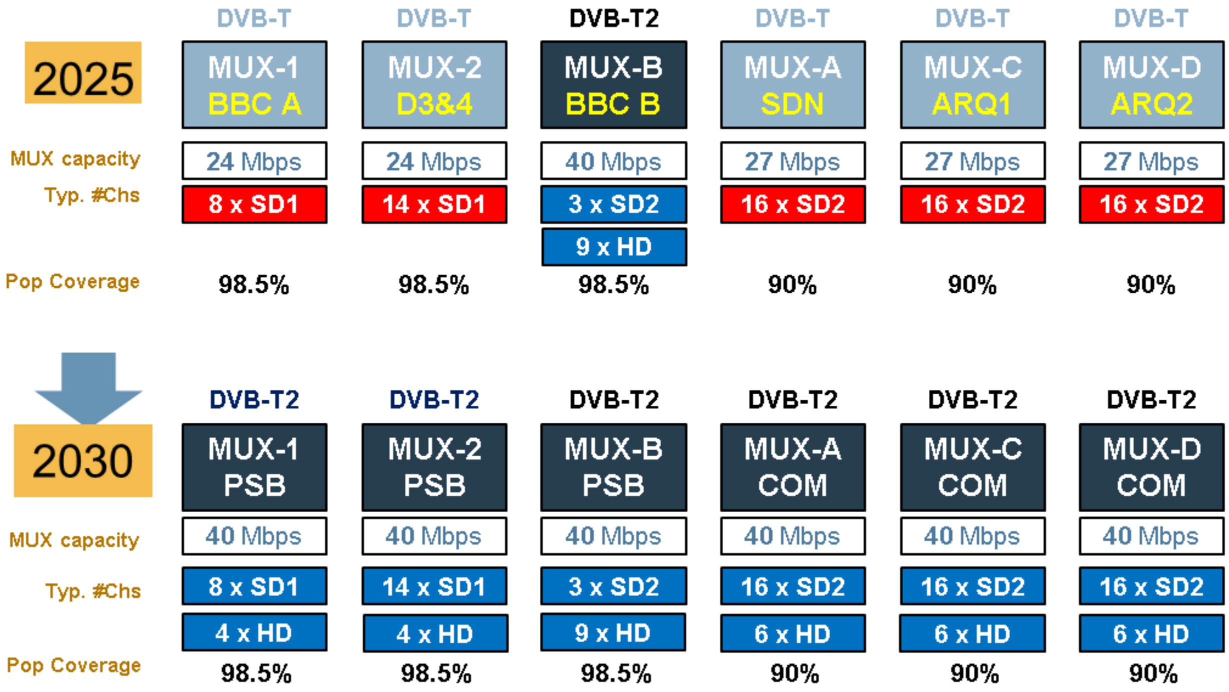
All DVB-T Multiplexes are upgraded to DVB-T2 including new Transmitter Power Amplifier equipment, and all content is encoded using MPEG4/AVC at some point between now and 2035, and we have assumed this might occur sometime before 2030. This case would apply where there was a justification and business case in providing extra capacity as additional TV channels, and/or higher quality TV content such as more HD channels on the DTT platform. This reflects what is happening in some other countries in Europe who have taken the decision to invest in their DTT platform. Ofcom's Future of TV distribution cites that Spain, France and Italy are taking steps to update their DTT networks to DVB-T2, and also HEVC video coding so that UHD content can be delivered. Of note, Spain has confirmed its move to DVB-T2[87].

In this case, as all six Multiplexes maintain their spectrum assignments across all DTT transmitters and there is no release of spectrum for IMT600 and there is no impact to how PMSE is used.

[86] https://www.broadbandtvnews.com/2024/10/28/rohde-schwarz-and-vantage-towers-team-up-for-5g-broadcast/

[87] https://www.broadbandtvnews.com/2025/03/26/spain-approves-move-to-dvb-t2 .

Exhibit 29: Invest in DTT for six DVB-T2/MPEG4 Multiplexes – case 1



Source: Coleago Consulting

The capital costs would include the upgrade of DVB-T2 equipment including Powe Amplifier components. We make the assumption there would not be any major re-engineering of the DTT sites required since existing antennas, combiners and RF components can be re-used. Although the illustration depicts 2030 for the upgrade step, such an upgrade can occur at any time. Of note we understand that from around 2027 all Patent Pool IP royalties should have expired for MPEG4/AVC, although this was not confirmed.

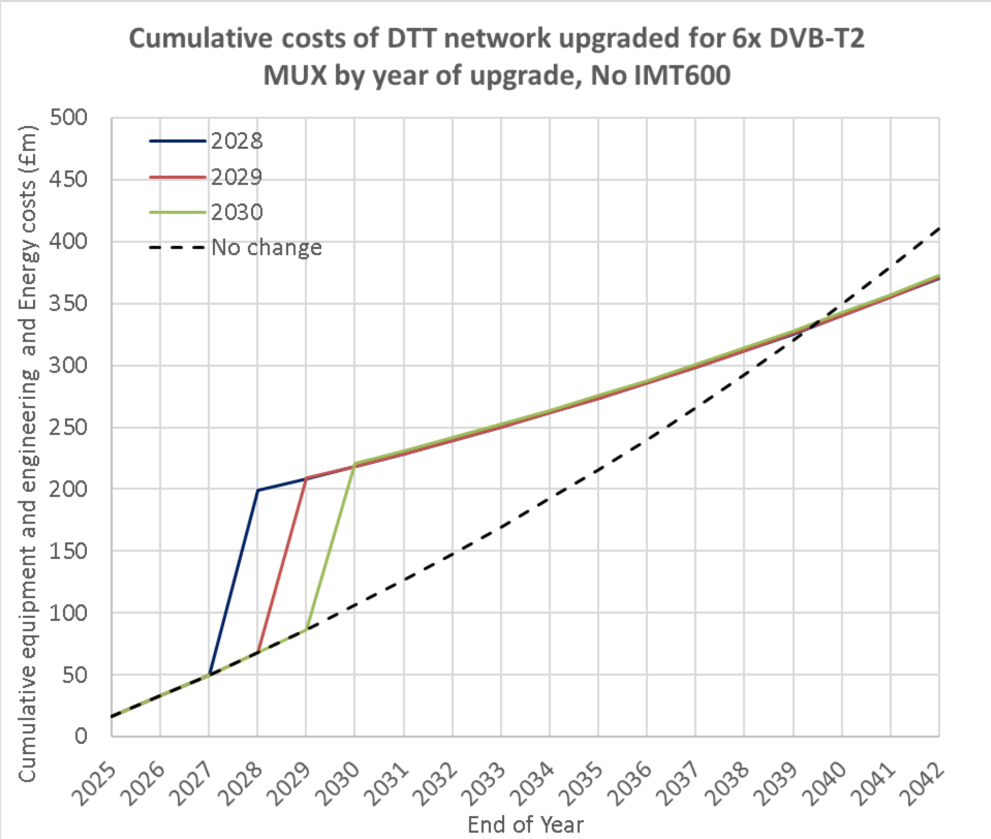
7.5.2 Cost estimation for case 1

Based on our assumptions that DVB-T2 transmitter equipment will be at least 50% energy efficient from and existing DVB-T transmitter (and current DVB-T2 MUX-B) equipment is only 25% energy efficient, we estimate this upgrade could translate to energy savings of **around £8M per year** across the DTT network.

We estimate the capital costs for deploying five new DVB-T2 transmitters at each of the 80 or so DTT main broadcast site to be **around £125M (as of 2025)**. We further estimate the subsidy costs associated with upgrading TV receivers would be **around £10M** based on 0.2 million Households with DVB-T only receivers as their primary TV device at £50 per household upgrade cost.

The chart below illustrates a simple illustration of cumulative costs associated with upgrading the DTT network to all DVB-T2 Multiplexes as a function of year of DTT network upgrade. Each curve represents the year of upgrade and the spikes in costs are related to spend on DVB-T2 infrastructure and DVB-T2 receiver upgrades, which for simplicity we assume occur in one year.

Exhibit 30: DTT Cost profile: invest in DTT for six DVB-T2/MPEG4 Multiplexes – case 1



Source: Coleago Consulting

The chart tells us that there is a marginal case in favour of upgrading the DTT network if deployment occurs before 2030 and the DTT platform remains until 2039. Deployment may take a couple of years (although we weren't able to seek such views) and hence the costs and relative savings in energy would be more dispersed. However, there of course would be the benefit to all consumers for additional channel capacity and/or HD content available from PSB and Commercial broadcasters.

Had this study taken place prior to the recent energy crisis from 2022 then the investment break-even cross-over would be beyond 2046 and may have concluded there would be no case to support an upgrade to purely reduce lifetime costs.

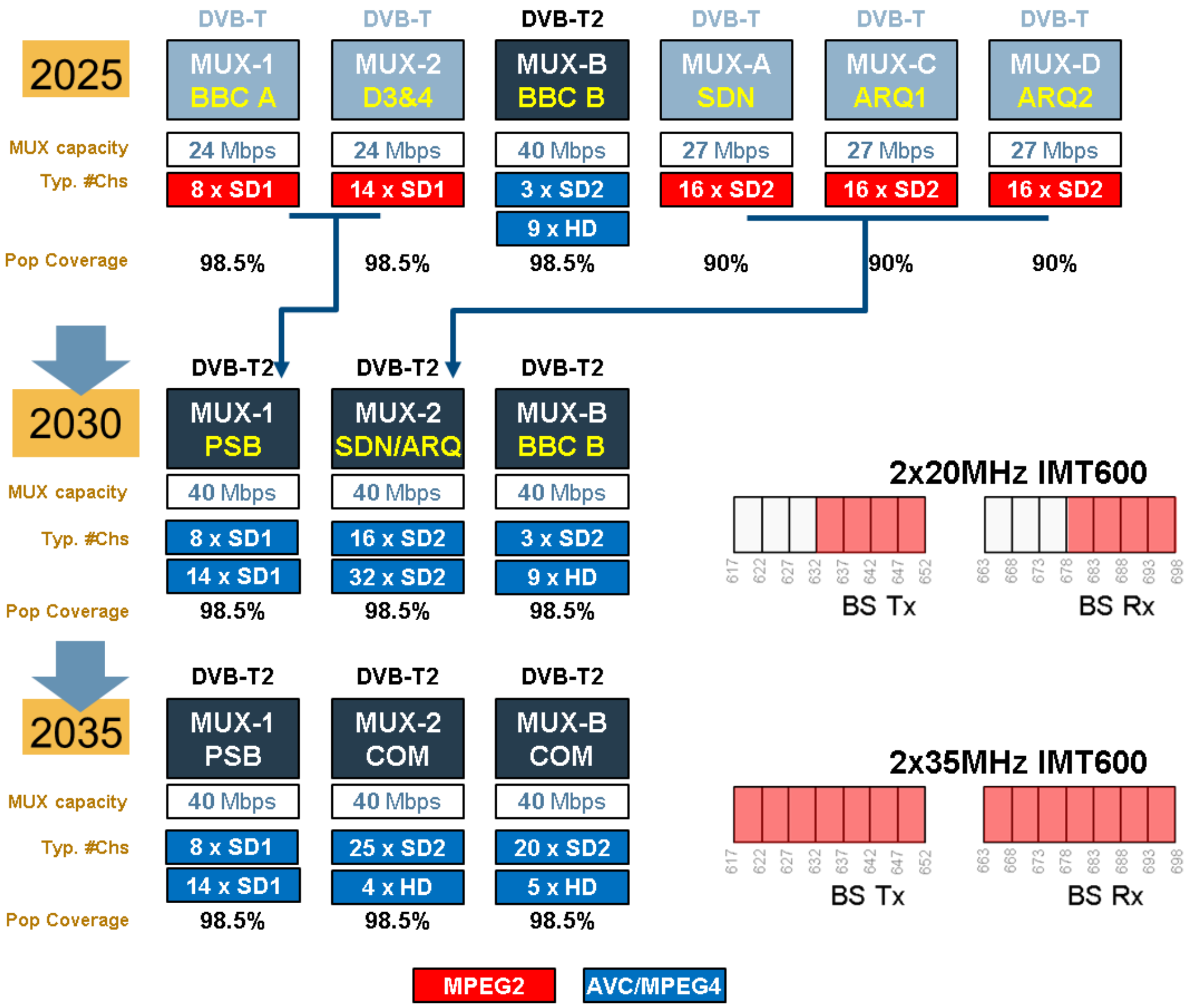
7.5.3 Case 2: Invest for three DVB-T2/MPEG4 Multiplexes

In this Case 2, two DVB-T Multiplexes are upgraded to DVB-T2 including new Transmitter Power Amplifier equipment, and all content is encoded using MPEG4/AVC, and three Multiplexes are removed. Despite reducing Multiplexers to three, this case preserves a similar total TV channel capacity to that of 2025. The current Multiplex licences would strictly run until end of 2034, and we assume the BBC would renew its MUX-B licence in 2026 until the end of 2034. However, an interim optional step is shown where the physical DTT network can be upgraded to DVB-T2 with MPEG4/AVC video coding earlier than 2035. In the illustration we show the upgrade in 2030.

If clear benefits in implementing an earlier upgrade could be demonstrated for all stakeholders (i.e. Multiplex licensees, PSB's, Arqiva) it would be reasonable to assume this step can occur along with appropriate consultation and agreement on how licences could be amended or adapted from 2030. In our illustration we have suggested that the Commercial Multiplex operators (SDN and Arqiva) share a single DVB-T2 Multiplex, which has approximately the same TV channel capacity as the three DVB-T/MPEG2 Multiplexes. Sharing running costs may prove a pragmatic step given the critical situation of running a DTT network. Sharing a Multiplex is synonymous with Radio Access Network (RAN) sharing in the cellular network world where costs are shared. An advantage for SDN and Arqiva is that the coverage footprint increases from 90% to 98.5% and therefore achieve ~10% increase in viewers and potentially this could translate to an increase in revenues from content providers.

The two DVB-T/MPEG2 PSB Multiplexes MUX-1 and MUX-2 are consolidated into one DVB-T2/MPEG4 as a single PSB Multiplex shared between BBC and D3&4. The BBC MUX-B remains as is and is not upgraded, although this could be contemplated for an upgrade also for energy efficiency reasons.

Exhibit 31: Invest in DTT for three DVB-T2/MPEG4 Multiplexes – case 2



Source: Coleago Consulting

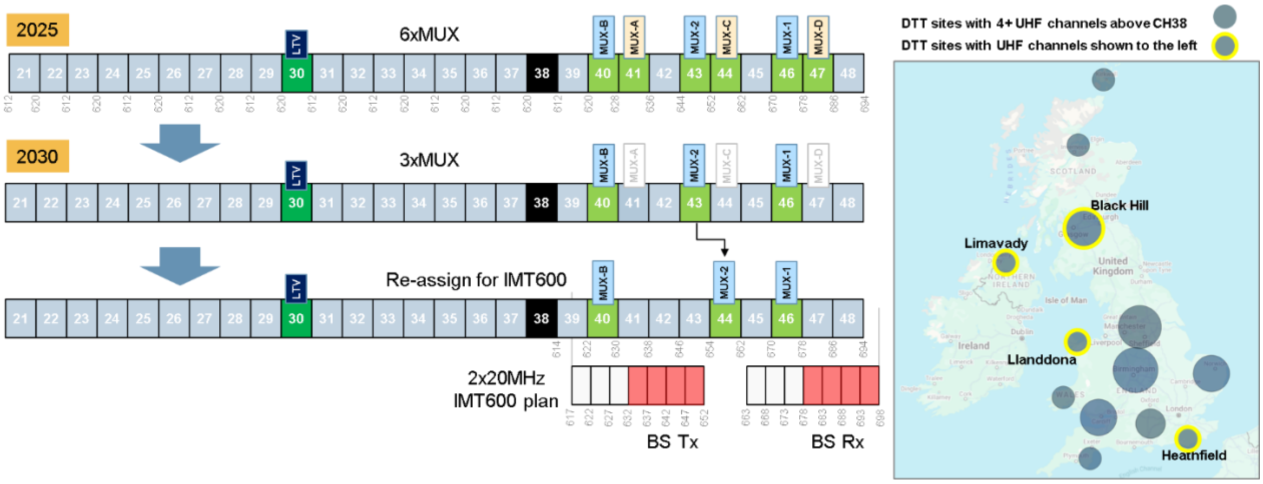
The motivation for DTT network investment in or before 2030 permits significant energy savings and at a reduced Capital cost when compared to Case 1, whilst also preserving or maintaining TV channel capacity. We assume there would not be any major re-engineering of the DTT sites required since existing antennas, combiners, UHF channel allotments and RF components all remain.

7.5.4 2 x 20 MHz release of IMT600 under case 2

In performing an upgrade of the DTT network by 2030, DTT spectrum is released. It may be possible to offer a spectrum dividend nationally of 2 x 20 MHz for an IMT600 band plan without major re-engineering of the DTT network, and without the need for changing DTT frequency allotments or international coordination. There are many advantages of introducing a partial IMT600 band early into the UK without requiring clearance efforts at a European coordinated level. Firstly, and perhaps most importantly offering 2 x 20 MHz to the market allows discovery of its value to the mobile operators through a competitive auction process for example. A release of 2 x 20 MHz may be sufficient for two operators rather than three UK operators, and it “tests the water” for extra low band appetite. In the event there were no bidders, or the reserve price was not met then this would demonstrate low value and a full and more expensive clearance of 600 MHz later in the 2030s may not be justified or warranted. If on the other hand, there is demand for 600 MHz from the mobile operators then this spectrum can be put to good use well ahead of any larger spectrum clearance efforts. The spectrum for IMT600 may also become co-primary with Broadcast by 2031 but this is a decision which would be determined at WRC-31. However, the UK may in principle decide whether to amend its National Frequency Plan ahead of WRC-31 as there would be likely be no or very little impact to other countries if the UK adopted a co-primary allocation for this portion of the spectrum since IMT to DTT interference is generally less impactful than DTT to IMT interference. We discuss this further later in the report in Section 4.

The exhibit below illustrates the concept of creating a national 2 x 20 MHz assignment within the IMT600 plan. Inspection of the DTT channel assignments across the UK reveal 13 main broadcast sites which have four or more UHF channels in the range 39-48 (out of the six Multiplexes at each main DTT site). We show the UHF channel assignments at four sites: Black Hill, Limavady, Llanddona and Heathfield. These sites use six UHF channels which fall into what would be the IMT600 band plan. Removing the three Multiplexes occupied by the three DVB-T Commercial Multiplexes as proposed in this case 2 means that UHF channels 40, 43, 46 remain. However, the DTT site still retains spectrum user rights for the UHF channels previously used by the DVB-T Commercial Multiplexes, and therefore we can re-assign MUX-2 from Channel 43 to Channel 44 as illustrated. MUX-2 may now be transmitting via a different a RF combiner and a different antenna array, depending upon how antenna and combiner systems are configured. If the antenna systems are identical in terms of radiation patterns, then moving Channel 43 to Channel 44 should not pose any issues. If, however, there were differences in radiation patterns between the different antenna systems, then Channel 43 can still be moved to Channel 44, but a new filter-combining system would be required to combine channels 40, 44, 46 onto what was the original PSB antenna system.

Exhibit 32: 2 x 20 MHz national assignment for IMT600 and maintain DTT spectrum usage rights for case 2



Source: Ofcom and Coleago Consulting

The precise use of combining and/or antenna systems at site would require further analysis on a site-by-site basis, but as there would be no major lift and shift re-engineering works expected or coordination work required, we would expect this to be relatively low cost. The other nine sites shown on the map have different UHF channel groups, but all can be shown, using channel re-assignments within the spectrum user rights, to free up the same 2 x 20 MHz IMT600 assignment nationally.

There would be a 2 MHz gap between the band edge of IMT600 base station transmit and the start of UHF channel 44. There is some risk of adjacent channel interference or TV Receiver blocking if IMT600 base stations may be close to TV receiver aerials. Additionally, there is no spectral gap between DTT Channel 46 and IMT600 Uplink. The DTG D-book and ETSI specifications require TV receivers to meet certain adjacent channel and blocking requirements for both IMT Base Station Downlink Transmit and Device Uplink Transmit cases. Since the introduction of 800 MHz for IMT, TV Receivers are generally much more robust in operating in the presence of IMT systems using adjacent spectrum. We however recommend that testing of a population of TV devices be conducted, by the DTG to better quantify if there are any potential risks of such interference. In corner cases, external in-line RF filters could also be deployed as was carried out for 800 MHz clearance and 700 MHz clearance when TV aerials might be very close to Base Station antennas (think of rooftops on blocks of flats). If for example, there was a risk of interference from devices to TV sets in areas using DTT channel 46, then 2 x 15 MHz could be adopted in these areas, or exploration of an alternative DTT channel, or offset channel 46 transmission within coordination rules.

In 2035, new Multiplexes can be offered if needed, and this can be one PSB and two Commercial Multiplexes as shown but could also include sharing of physical Multiplexes. The specific Multiplex licence model from 2035 is not critical for this study. In 2035, we show a full clearance of 600 MHz but the decision on whether this should be done can be informed from what plays out from 2030. How much demand or value is placed on the 2x20 MHz offered in 2030? Where is the UK TV industry at in terms of IPTV and DTT, where are our neighbours and Europe in general regarding decisions and thinking for IMT600, and what are the successes or lessons learnt from other countries adopting DVB-T2/HEVC?

7.5.5 PMSE spectrum under case 2

If a 2 x 20 MHz IMT600 plan was released with a 3x DTT Multiplex network (plus 1x Local TV Multiplex), then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 138 MHz. We assume here that 56 MHz would be effectively sterilised for PMSE use rather than 2 x 20 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges, but there are now also three 8 MHz UHF channels = 24 MHz not being used by DTT. Thus 170 MHz – 56 MHz + 24 MHz = 138 MHz. Our analysis of PMSE UHF licence data indicates that there were 24 locations nationally during the 12-months in 2024 which had greater than 138 MHz (17 locations with short duration licences and 6 locations with long duration licences).

If the 2 x 35 MHz full IMT600 plan was released with a 3x DTT Multiplex network, then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 106 MHz. We assume here that 88 MHz would be effectively sterilised for PMSE use rather than 2x35 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges and unable to use the IMT600 duplex gap, but there are now also three 8 MHz UHF channels = 24 MHz not being used by DTT. Thus 170 MHz – 88 MHz + 24 MHz = 106 MHz. Our analysis of PMSE UHF licence data indicates that there were 46 locations nationally during the 12-months in 2024 which had greater than 106 MHz (34 locations with short duration licences and 11 locations with long duration licences).

PMSE spectrum limitation mitigation options could include:

- More intensive re-use in time and location of existing PMSE licences,
- Deployment of WMAS solutions (which also could facilitate the above item),
- Use of the 960-1154 MHz band (if not already used at these locations),
- Exploration of using 733-758 MHz as temporary leased spectrum,
- Geographic/time coordination between PMSE and IMT600, where IMT600 is Secondary to PMSE

A mixture of these mitigation approaches can be applied of course, and the release of 2 x 20 MHz from 2030 should allow for a more gradual migration of mitigation options, but also an important review of PMSE demand and PMSE capacity solutions might be. In the limit, the Geographic and time-sharing approach alone should allow PMSE additional spectrum at these high-demand locations and therefore always promise that PMSE spectrum value can be maximised. In reality, a mixture of techniques and technologies would reduce the reliance on any geographic/time sharing of PMSE and IMT600.

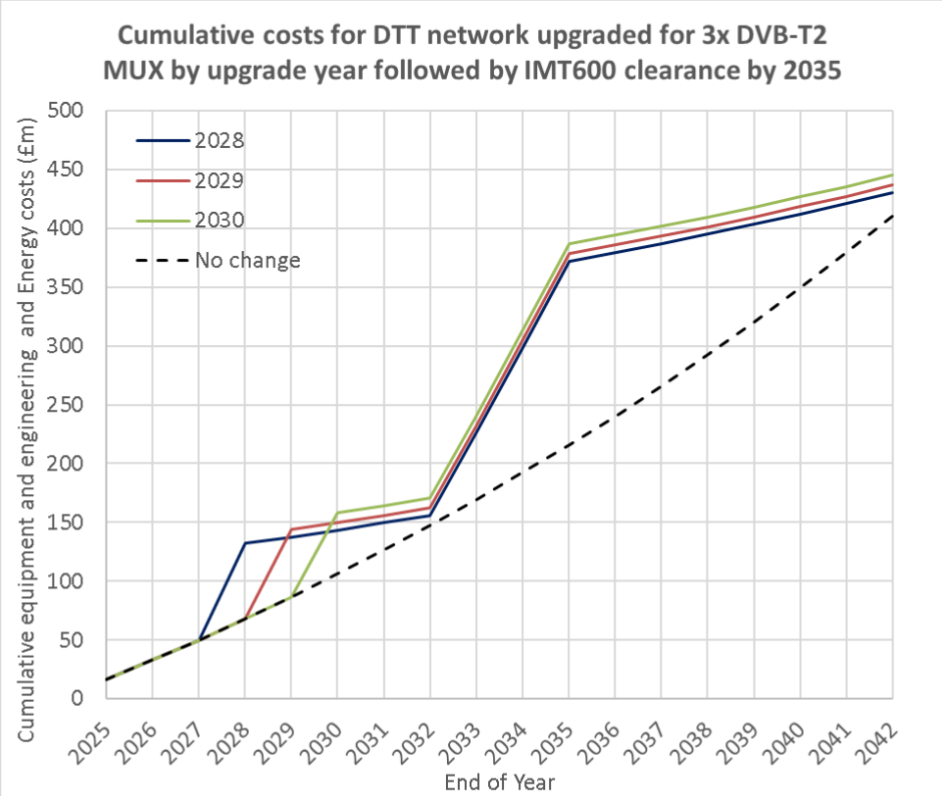
7.5.6 Cost estimation for case 2

Based on our assumptions that DVB-T2 transmitter equipment will be at least 50% energy efficient from and existing DVB-T transmitter (and current DVB-T2 MUX-B) equipment is only 25% energy efficient, we estimate this upgrade could translate to energy **savings of around £11M per year** across the DTT network.

We estimate the capital costs for deploying two new DVB-T2 transmitters at each of the 80 or so DTT main broadcast site to be **around £50M (as of 2025)**. We further estimate the subsidy costs associated with upgrading TV receivers **would be £5M** based on 0.2 million Households with DVB-T only receivers as their primary TV device at £25 per household upgrade cost.

The chart below illustrates a simple illustration of cumulative costs associated with upgrading the DTT network so there are a total of three DVB-T2 Multiplexes as a function of year of DTT network upgrade. Each curve represents the year of upgrade and the spikes in costs are related to spend on DVB-T2 infrastructure and DVB-T2 receiver upgrades, which for simplicity we assume occur in one year.

Exhibit 33: DTT Cost profile: invest for three DVB-T2/MPEG4 Multiplexes – case 2



Source: Coleago Consulting

The chart tells us that there could be a favourable argument in upgrading the DTT network if it is sustained until 2035 due to the reduced energy costs in using only three Multiplexes and using two new transmitters. The savings in energy costs help justify the capital investment whilst maintaining TV channel capacity. The chart also shows a second wave of investment from 2032-2035 for full IMT600 clearance. However, due to continued energy costs savings, this investment could also be largely paid back by 2042. In short, the current DTT network could (1) continue in its current form until 2042, or (2) receive investment, maintain the same quantity of channels, benefit from an early release of IMT600 by 2030, and a full release of IMT600 later in the 2030s.

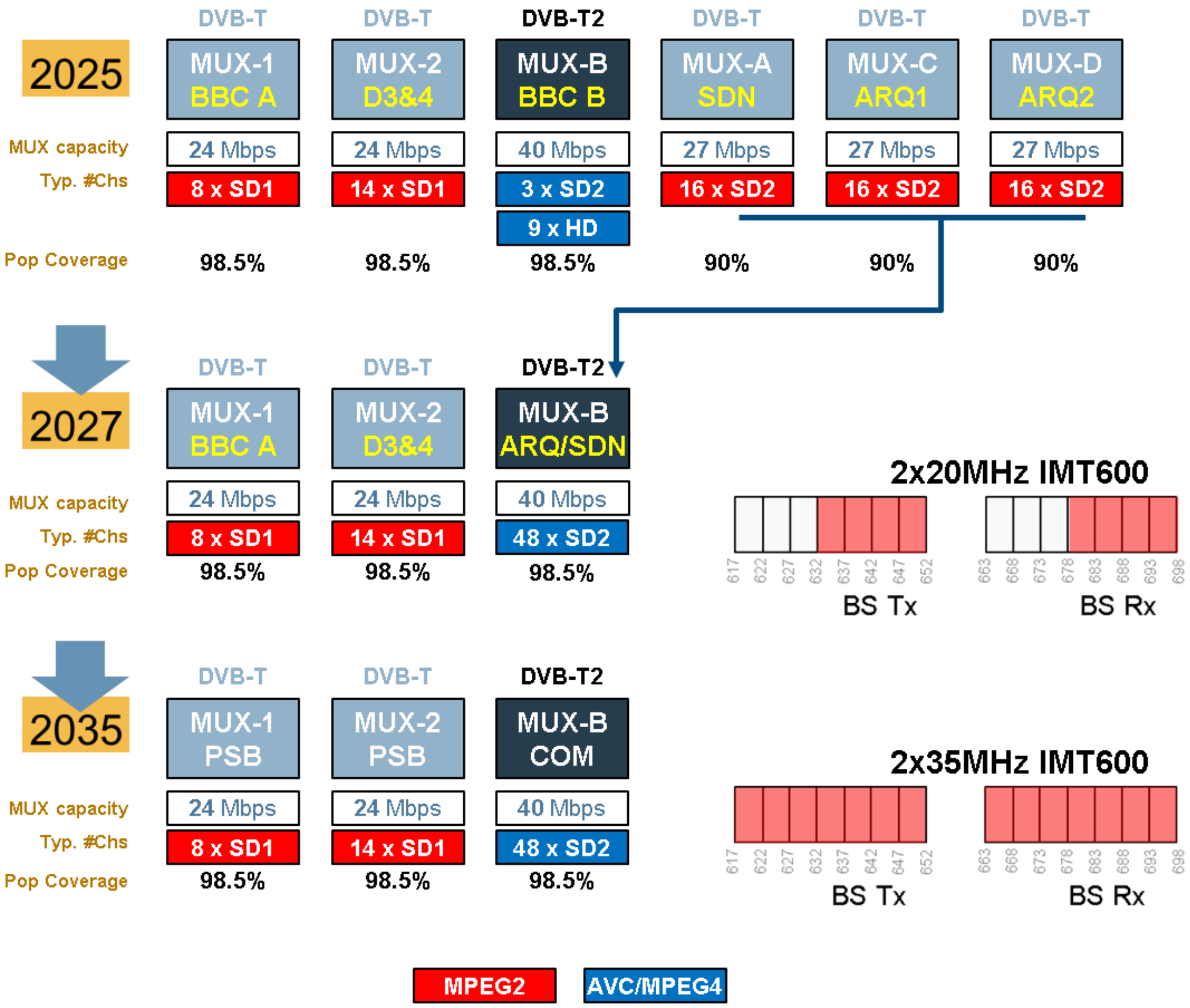
7.6 Ofcom Scenario 2 – Reduce DTT to a core service

7.6.1 Case 3: Reduce DTT to three existing Multiplexes

In this Case 3, none of the Multiplexes are upgraded to DVB-T2/MPEG2 and there are no video coding upgrades either, but three Multiplexes are removed. This case 3 reflects the very possible situation where the MUX-B licence, due to expire at the end of 2026, is not renewed by the BBC. Currently, all Multiplex operators have renewed until Dec 2034, but the BBC wishes to hold back on a decision for renewal of MUX-B so it can be best informed[88]

In this Case 3 we propose that the Commercial Multiplex operators, SDN and Arqiva might share the vacated MUX-B slot and take advantage of lower running costs, improved coverage footprint, and with about the same overall TV channel capacity as illustrated. SDN and Arqiva would not be able to reach households with DVB-T only receivers which might only be around 0.5m households from 2027, so the extra 10% in population coverage should outweigh the loss in consumers with DVB-T only receivers.

Exhibit 34: Reduce DTT to three existing Multiplexes – case 3



Source: Coleago Consulting

From 2027, and as described for Case 2 using three Multiplexes, it can be possible for a national assignment of 2 x 20 MHz in an IMT600 band plan to be created whilst preserving existing spectrum usage rights and channel allotments. An early release of IMT600 spectrum from 2027 could be offered to the mobile operators as valuable additional low band spectrum.

88 https://rxtvinfo.com/2025/freeview-hd-channels-could-be-cut-next-year/

The 600 MHz could be licenced to one or two operators or another entity which might allow wholesale access, or a consortium of operators sharing the spectrum using a MOCN network architecture. How the spectrum might be used could be item for industry consultation if this case 3 outcome was a likely outcome or preferred route. The 2x20 MHz of 600 MHz can be offered at any time from 2027 but might be offered say in 2031 following consultation processes and potential co-primary status allocation from WRC-31 or offered from 2027 in locations where there would be be no risk of interference to DTT receivers in France or Ireland.

In 2035, new Multiplexes can be offered if needed, and this can be two PSB Multiplexes and one Commercial Multiplex as shown but could also include sharing of physical Multiplexes. The specific Multiplex licence model from 2035 is not critical for this study. In 2035, we show a full clearance of 600 MHz but the decision on whether this should be done can be informed from what plays out from 2027. How much demand or value is placed on the 2x20 MHz offered from 2027? Where is the UK TV industry at in terms of IPTV and DTT, where are our neighbours and Europe in general regarding decisions and thinking for IMT600, and what are the successes or lessons learnt from other countries adopting DVB-T2/HEVC?

7.6.2 PMSE spectrum under case 3

The impact to PMSE spectrum will be the same as for Case 2. For simplicity, we repeat our analysis below.

If a 2 x 20 MHz IMT600 plan was released with a 3x DTT Multiplex network (plus 1x Local TV Multiplex), then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 138 MHz. We assume here that 56 MHz would be effectively sterilised for PMSE use rather than 2x20 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges, but there are now also three 8 MHz UHF channels = 24 MHz not being used by DTT. Thus 170 MHz – 56 MHz + 24 MHz = 138 MHz. Our analysis of PMSE UHF licence data indicates that there were 24 locations nationally during the 12-months in 2024 which had greater than 138 MHz (17 locations with short duration licences and 6 locations with long duration licences).

If the 2 x 35 MHz full IMT600 plan was released with a 3x DTT Multiplex network, then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 106 MHz. We assume here that 88 MHz would be effectively sterilised for PMSE use rather than 2x35 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges and unable to use the IMT600 duplex gap, but there are now also three 8 MHz UHF channels = 24 MHz not being used by DTT. Thus 170 MHz – 88 MHz + 24 MHz = 106 MHz. Our analysis of PMSE UHF licence data indicates that there were 46 locations nationally during the 12-months in 2024 which had greater than 106 MHz (34 locations with short duration licences and 11 locations with long duration licences).

PMSE spectrum limitation mitigation options could include:

- More intensive re-use in time and location of existing PMSE licences
- Deployment of WMAS solutions (which also could facilitate the above item)
- Use of the 960-1154 MHz band (if not already used at these locations)
- Exploration of using 733-758 MHz as temporary leased spectrum
- Geographic/time coordination between PMSE and IMT600, where IMT600 is Secondary to PMSE

A mixture of these mitigation approaches can be applied of course, and the release of 2 x 20 MHz from 2030 should allow for a more gradual migration of mitigation options, but also an important review of PMSE demand and PMSE capacity solutions might be. In the limit, the Geographic and time-sharing approach alone should allow PMSE additional spectrum at these high-demand locations and therefore always promise that PMSE spectrum value can be maximised. In reality, a mixture of techniques and technologies would reduce the reliance on any geographic/time sharing of PMSE and IMT600.

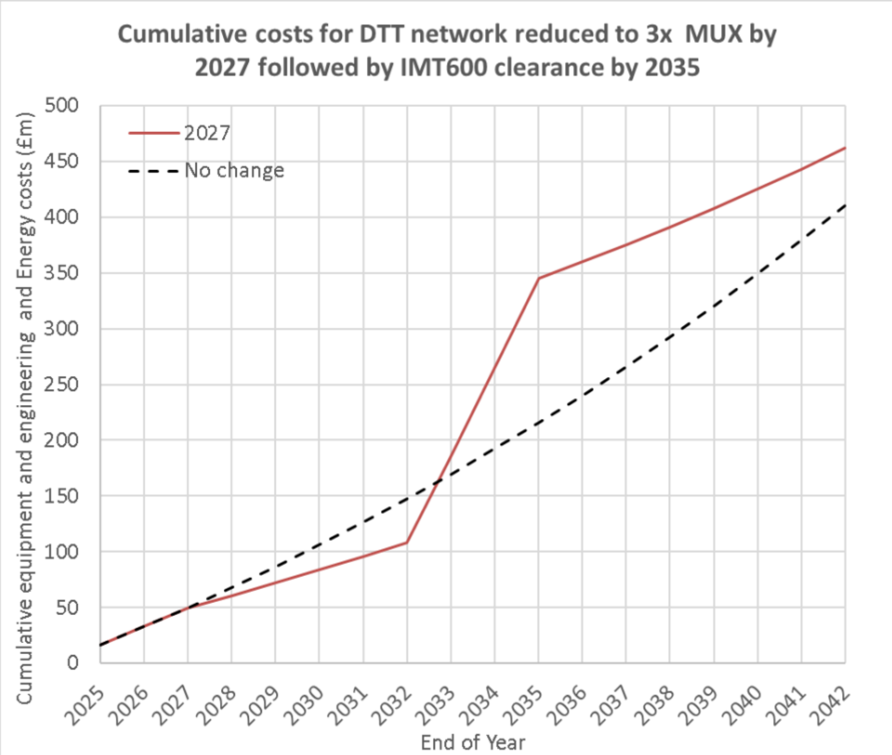
7.6.3 Cost estimation for case 3

Based on our assumptions that the two existing DVB-T and one existing DVB-T2 equipment are only 25% energy efficient, the savings in energy are simply due to the reduction in the number of Multiplexes. We estimate energy savings of **around £6.5M per year** across the DTT network from 2027.

There are no significant capital costs as there is no upgrade to the DTT network. There would be some decommission costs to consider and possibly some consolidation in DTT combining configurations at DTT sites if a 2x20 MHz IMT600 release was considered, but we expect this would be relatively small. There would be no need for subsidies associated with upgrading TV receivers also.

The chart below illustrates a simple illustration of cumulative costs associated with reducing the DTT network to three Multiplexes from 2027.

Exhibit 35: Cost profile: reduce DTT to three existing Multiplexes – case 3



Source: Coleago Consulting

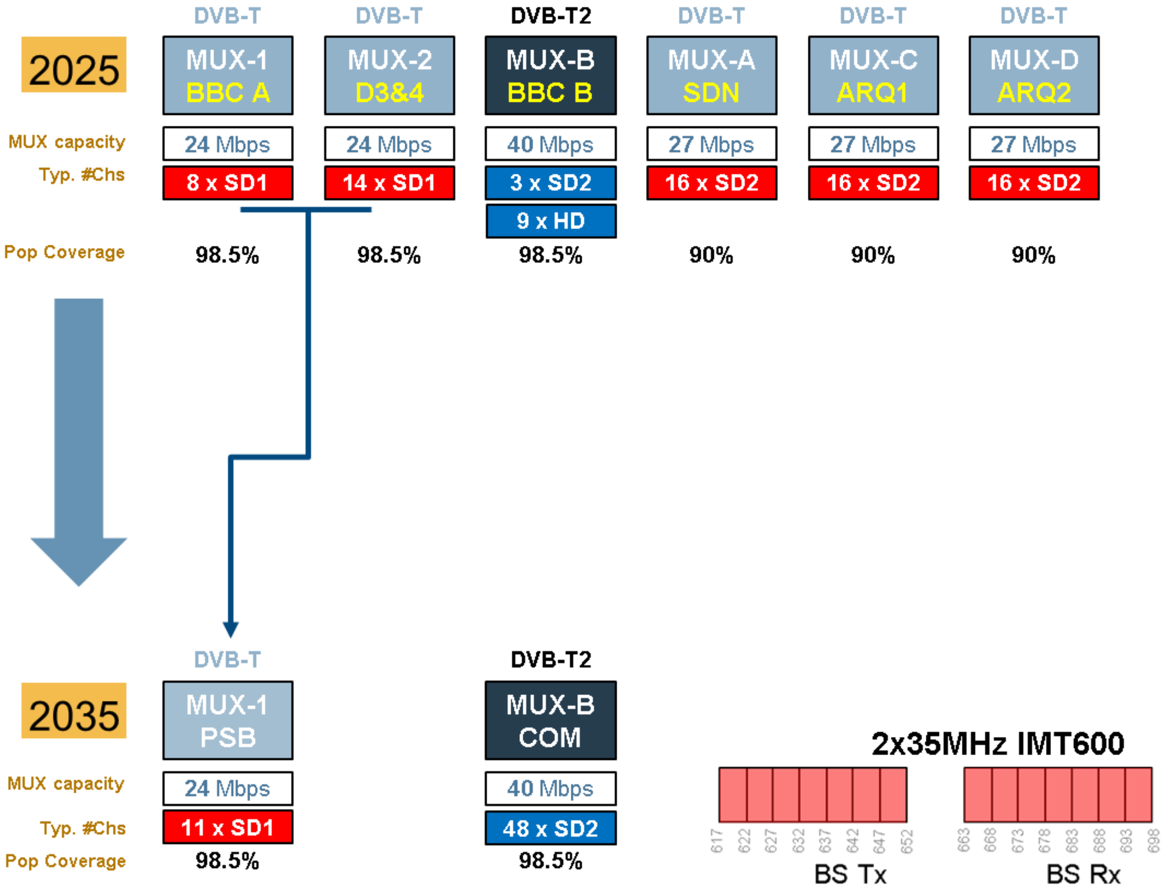
The chart tells us that there are some savings from 2027 due to the reduced number of Multiplexes to three, followed by a cost spike associated with IMT600 clearance starting in 2032 and completing in 2035.

7.6.4 Case 4: Reduce DTT to two existing Multiplexes

In this Case 4, none of the Multiplexes are upgraded to DVB-T2/MPEG2 and there are no video coding upgrades either, but four Multiplexes are removed at the end of the current Multiplex licence period (Dec 2034). Unlike Case 3, this case 4 assumes that the BBC does renew its MUX-B licence, which due to expire at the end of 2026.

In this Case 4 there is no consolidation of Multiplexes or services between 2025 and 2035. Whether this is a likely outcome is open for further debate, but like Case 1, it serves more as a reference case where there is no intervention until 2035. As such, there is no interim release of 600 MHz band as illustrated for Cases 2 and 3. Instead, we assume that DTT reduces to a night-light service from 2035 with a full IMT600 band plan being implemented from 2035.

Exhibit 36: Reduce DTT to two existing Multiplexes – case 4



Source: Coleago Consulting

In 2035, two new Multiplexes can be offered if needed, and this can be one PSB and one Commercial Multiplex as shown but could also include sharing of physical Multiplexes too. The specific Multiplex licence model beyond 2035 is not critical for this study. We show that the BBC and D3&4 share a single DVB-T/MPEG2 Multiplex perhaps supporting 11 SD1 TV channels which would be the top 11 PSB channels, which we estimate to represent over 95% of all PSB viewing as of 2024. The Commercial Multiplex is shown as 48 SD2 TV channels carried on the DVB-T2/MPEG4 Multiplex which is similar capacity to the existing three DVB-T/MPEG2 Multiplexes. The Commercial Multiplex would also benefit from increased coverage footprint relative to current Commercial Multiplexes. There is no HD content transmitted. The Commercial Multiplex could carry any additional PSB TV channels on a commercial basis if needed of course. This Case 4 illustrates that if HD content was omitted then almost all of the viewing minutes could be met using two existing Multiplexes, which we are considering as a night-light service.

It is also possible to reduce the number of Multiplexes before 2035, as was depicted in Cases 2 and 3, as an interim step perhaps around 2030. This would not enable any more that 2 x 20 MHz of IMT600 to be made available nationally without having to engage in coordination and re-engineering efforts. It can be shown that 2 x 25 MHz could be released whilst preserving Spectrum usage rights within existing DTT frequency allotments but requires that this be a different 2 x 25 MHz assignment within the service areas of four main DTT broadcast sites.

It is also possible to consider reducing the DTT to one Multiplex. If the DVB-T2/MPEG4 Multiplex is kept from 2035, then this provides around three times the TV channel capacity as the single DVB-T/MPEG2 Multiplex. The question of upgrading DVB-T only households by 2035 would still need to be addressed although we estimate the number of households with DVB-T only as their primary TV set to be around 50,000 by 2035. If the DVB-T/MPEG2 is kept then TV set upgrades are not required but perhaps only able to support say 6 Channels of PSB and 6 Channels of Commercial TV content, along with some Radio services. Under a single Multiplex case, it becomes possible to free up a common 2 x 30 MHz assignment nationally whilst maintaining Spectrum User rights within existing DTT Frequency allotments.

7.6.5 PMSE spectrum under case 4

If the 2 x 35 MHz full IMT600 plan was released with a 2x DTT Multiplex network (plus 1x Local TV Multiplex), then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 114 MHz. We assume here that 88 MHz would be effectively sterilised for PMSE use rather than 2 x 35 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges and unable to use the IMT600 duplex gap, but there are now also four 8 MHz UHF channels = 32 MHz not being used by DTT. Thus 170 MHz – 88 MHz + 32 MHz = 114 MHz. Our analysis of PMSE UHF licence data indicates that there were 46 locations nationally during the 12-months in 2024 which had greater than 106 MHz (28 locations with short duration licences and 9 locations with long duration licences).

As stated for Cases 2 and 3, PMSE spectrum limitation mitigation options could include:

- More intensive re-use in time and location of existing PMSE licences
- Deployment of WMAS solutions (which also could facilitate the above item)
- Use of the 960-1154 MHz band (if not already used at these locations)
- Exploration of using 733-758 MHz as temporary leased spectrum
- Geographic/time coordination between PMSE and IMT600, where IMT600 is Secondary to PMSE

A mixture of these mitigation approaches can be applied of course. It will be important to review PMSE demand and how effective various proposed PMSE capacity solutions might be each year. In the limit, the Geographic and time-sharing approach alone should allow PMSE additional spectrum at these high-demand locations and therefore always promise that PMSE spectrum value can be maximised. A mixture of techniques and technologies would reduce the need to rely on any large scale geographic/time sharing of PMSE and IMT600.

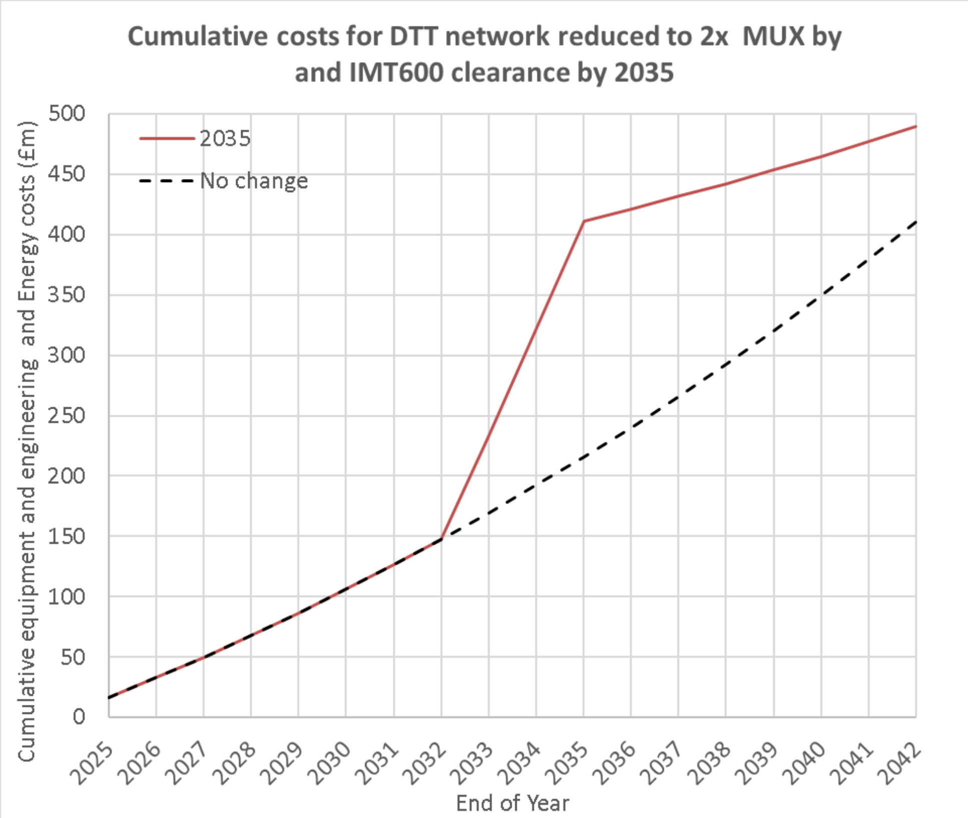
7.6.6 Cost estimation for case 4

Based on our assumptions that the two existing DVB-T and one existing DVB-T2 equipment are only 25% energy efficient, the savings in energy are simply due to the reduction in the number of Multiplexes. We estimate energy savings of **around £9.4M per year** across the DTT network from 2035.

There are no significant capital costs as there is no upgrade to the DTT network. There would be some decommission costs to consider and possibly some consolidation in combining UHF channels onto remaining antenna systems, but this would be expected to be relatively small. There would be no need for subsidies associated with upgrading TV receivers also.

The chart below illustrates a simple illustration of cumulative costs associated with reducing the DTT network to two Multiplexes from 2035.

Exhibit 37: Cost profile: reduce DTT to three existing Multiplexes – case 4



Source: Coleago Consulting

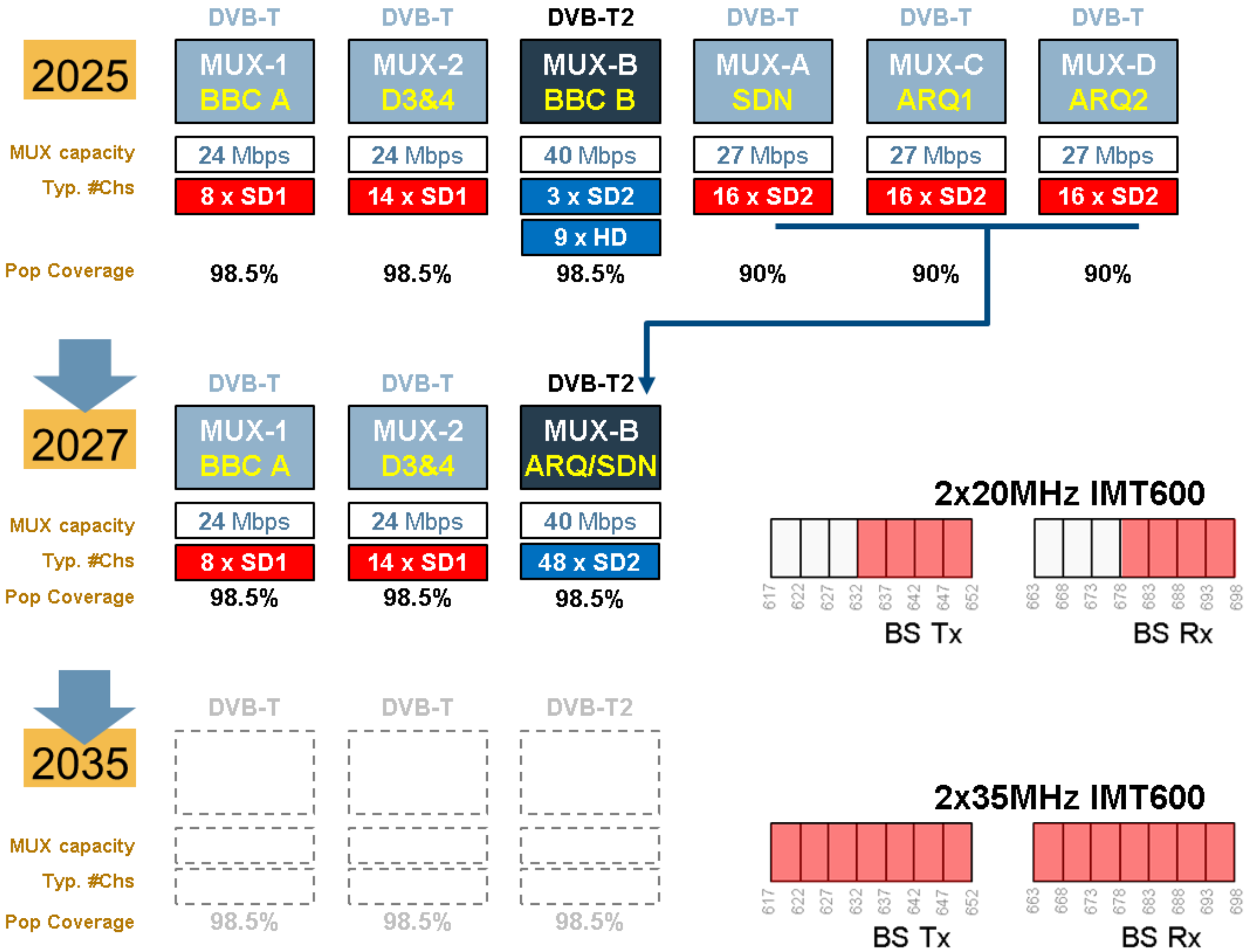
The chart tells us that there are no savings in energy until 2035, accompanied by a cost spike associated with IMT600 clearance starting in 2032 and completing in 2035.

7.7 Ofcom Scenario 3 – Transition to IPTV

7.7.1 Case 5: Remove DTT

In this Case 7, a complete transition to IPTV is assumed from 2035. The transition may also include more extensive use of Satellite TV delivery to ensure Universality and Reliability can be met. In Case 5 it is also assumed that the BBC decides not to renew its MUX-B Multiplex licence due for renewal toward the end of 2026. This non-renewal by the BBC was also contemplated as part of case 3 too where the DTT network reduces to a core service. As with Case 3, we assume that Commercial Multiplex operators SDN and Arqiva may be able to take over the vacated MUX-B layer in the DTT network from 2027. The TV channel capacity from the single DVB-T2/MPEG4 Multiplex offers about the same TV Channel capacity as three DVB-T/MPEG2 Multiplexes. Additionally, SDN and Arqiva have improved coverage.

Exhibit 38: Remove DTT from 2035 – case 5



Source: Coleago Consulting

From 2027, it also becomes feasible to offer 2 x 20 MHz national assignment in the IMT600 band whilst preserving DTT internationally agreed frequency allotments and hence not needing to re-plan frequencies for the DTT network. When to offer such 2 x 20 MHz may be a subject of further debate or industry consultation. The UK National Frequency Allocation Table currently has Land Mobile service (which includes IMT) as a Secondary allocation to Broadcast which has a Primary allocation status, and this is unlikely to change before 2031. A Secondary allocation means that IMT is not able to claim protection from harmful interference from the Broadcast service, nor can IMT cause harmful interference to the Broadcast service in the UK and to neighbouring countries. These interference aspects are considered in the next section in more detail. Should the Mobile industry wait until 2031 when there may be a co-Primary allocation decision made, or would the mobile industry want to see earlier release of IMT600 albeit with Secondary allocation status? The timing of IMT600 will also depend upon neighbouring country's decisions too. If for example, France, Ireland, Belgium, the Netherlands and the UK sought co-Primary allocation status from 2031 then presumably there might renewed bilateral agreements which can be developed which provide protection to and from IMT networks in the respective countries.

Whilst our study focuses on the spectrum use for the various cases, it should be noted that any substituting of DTT with IPTV, the additional traffic absorption into broadband networks is a vital consideration. IPTV delivery into millions of additional homes needs to factor in aspects such as quality, reliability and the management of peak events being appropriately managed. In Case 5, significant investment is required to ensure that resilience of the IPTV matches that of the DTT network. We don't make estimates as to the costs for such resilience and carrying additional traffic, but the costs are there, nonetheless. These IPTV upgrade costs should be the subject of further separate study and debate if not already being carried out already by Government in their deliberations for policy of future TV distribution.

7.7.2 PMSE spectrum under case 5

If a 2 x 20 MHz IMT600 plan was released with a 3x DTT Multiplex (plus 1x Local TV Multiplex) network, then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 138 MHz. We assume here that 56 MHz would be effectively sterilised for PMSE use rather than 2 x 20 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges, but there are now also three 8 MHz UHF channels = 24 MHz not being used by DTT. Thus 170 MHz – 56 MHz + 24 MHz = 138 MHz. Our analysis of PMSE UHF licence data indicates that there were 24 locations nationally during the 12-months in 2024 which had greater than 138 MHz (17 locations with short duration licences and six locations with long duration licences).

If the 2 x 35 MHz full IMT600 plan was released with a 2x DTT Multiplex network, then the available spectrum for PMSE would reduce from its current maximum of 170 MHz to around 114 MHz. We assume here that 88 MHz would be effectively sterilised for PMSE use rather than 2 x 35 MHz since we have assumed PMSE devices need to be at least 4 MHz away from IMT band edges and unable to use the IMT600 duplex gap, but there are now also seven 8 MHz UHF channels = 56 MHz not being used by DTT (6 main Multiplexes plus Local TV Multiplex). Thus 170 MHz – 88 MHz + 56 MHz = 138 MHz. This means there would be no change from the 2 x 20 MHz IMT600 plan co-existing with 3x DTT Multiplexes

As stated for Cases 2, 3, and 4 PMSE spectrum limitation mitigation options could include:

- More intensive re-use in time and location of existing PMSE licences
- Deployment of WMAS solutions (which also could facilitate the above item)
- Use of the 960-1154 MHz band (if not already used at these locations)
- Exploration of using 733-758 MHz as temporary leased spectrum
- Geographic/time coordination between PMSE and IMT600, where IMT600 is Secondary to PMSE

A mixture of these mitigation approaches can be applied of course. It will be important to review PMSE demand and how effective various proposed PMSE capacity solutions might be each year. In the limit, the Geographic and time-sharing approach alone should allow PMSE additional spectrum at these high-demand locations and therefore always promise that PMSE spectrum value can be maximised. A mixture of techniques and technologies would reduce the need to rely on any large scale geographic/time sharing of PMSE and IMT600.

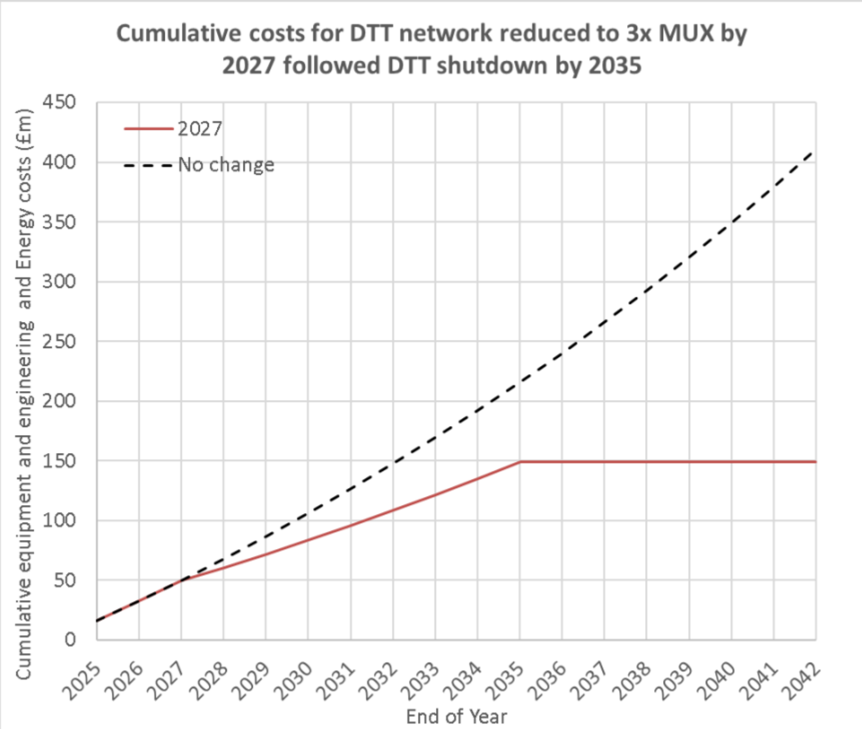
If the entire DTT network was shut down, and a full 2x35 MHz IMT600 band plan implemented then there could be a surplus of spectrum in the 470-606 MHz range. Only PMSE could usefully exploit this spectrum yet could only use it in concentrated locations and times, as is the nature of PMSE use. Ending up with a surplus of spectrum in a band with excellent propagation characteristics may be viewed as poor use of an otherwise valuable resource. There are no active discussions looking into a 500 MHz band for IMT, although the topic has been debated in the US where DTT is less prevalent and IMT600 has been licenced for several years now. 3GPP has specified bands 107 and 108 recently as Standalone Downlink Only (SDO) for 5G Broadcast applications.

If there was a potential risk for a spectrum surplus, then maintaining at least one DVB-T and/or one DVB-T2 Multiplex may be a pragmatic solution as per case 4. Running costs would become a key factor in whether this is viable as a standalone business or whether such a network is subsidised by other public funding. Investment into highest efficiency transmitters may be the appropriate path to ensure that spectrum can be usefully maintained for the benefit of all.

7.7.3 Cost estimation for case 5

From 2035, the remaining DTT Multiplexes are shut down, including Local TV Multiplex licences and where IPTV, Satellite and Cable must deliver the TV services to the UK population. Since the DTT network is being closed in this case 5, there are no DTT network frequency repacking costs. There are also no ongoing energy costs for DTT, although there would be significant capital costs and energy costs associated with any national scale IPTV platform. This report does not attempt to estimate costs for IPTV as this is beyond the scope of the research although there are other studies informing DCMS on such costs. As with all the other cases presented in this report, investment in IPTV will be ongoing where IPTV is both a competitive and a complementary delivery platform to DTT for delivery of TV services, rather than a replacement platform.

Exhibit 39: Cost profile: switch off DTT – case 5



Source: Coleago Consulting

The chart for Case 5 is somewhat arbitrary as ongoing costs cease from 2035. There would be de-commissioning costs to consider, although we have not factored these into our analysis.

7.8 IMT600 co-existence with DTT considerations

Assuming DTT spectrum is reduced as proposed in our Cases 2, 3, 4, and 5 there also needs to be reasonable confidence that IMT services could co-exist with the UK DTT network and more importantly with DTT networks in Ireland, France, the Netherlands and Belgium, in the event there is not any harmonised coordination to release 600 MHz for IMT across Europe.

7.8.1 UK DTT Receiver co-existence with UK IMT600 Downlink

We have assumed and proposed that UHF channel 44 is maintained for DTT in all our cases as Channel 44 falls directly into the IMT600 duplex gap and affords some efficiency for using the UHF spectrum between IMT and DTT. As discussed at case 2 we recommend that adjacent channel rejection and blocking performance of existing TV sets might be tested by DTG to confirm co-existence between IMT600 and DTT using Channel 44. It may also be prudent to understand what RF filters may be needed to reject IMT600 from TV receivers. Vendors such as Filtronics and Radio Design provided solutions previously, most notably for the 800 MHz clearance. Any filtering would however be a little more complex than for the filter solutions used for 800 MHz co-existence as the TV pass band needs to be in two parts – Channel 44 and Channels 21-37.

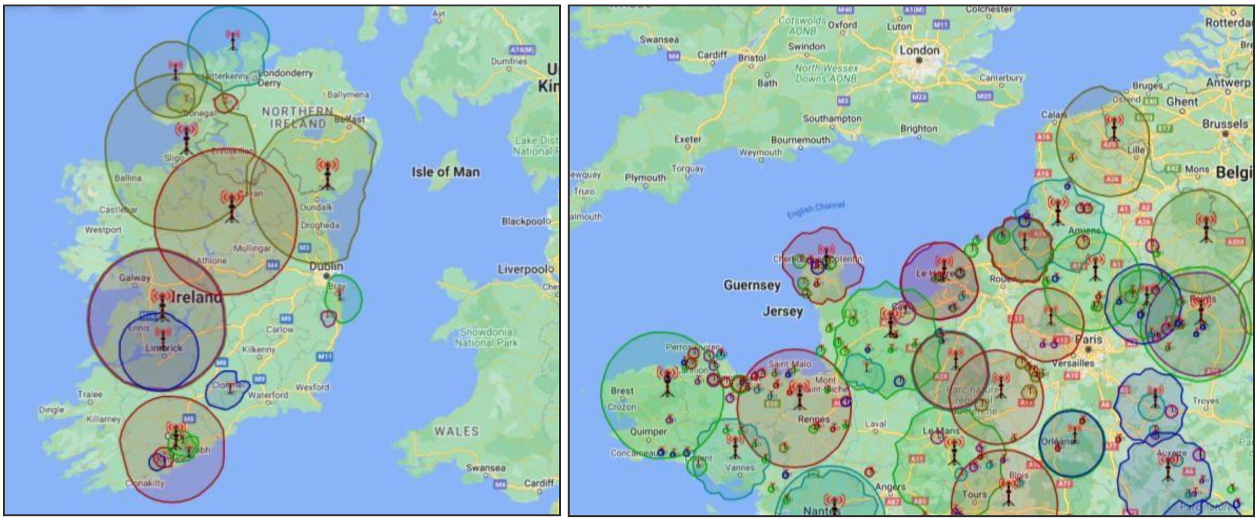
7.8.2 UK IMT600 Uplink co-existence with International DTT

The key interference mechanism for DTT and IMT600 FDD co-existence is the risk of interference from DTT Transmitters outside of the UK which would be co-channel to the IMT600 FDD Uplink. This is typically claimed by some proponents as the overarching reason preventing a co-primary allocation. The worst-case conditions arise when a High Power/High Tower DTT broadcast transmitter in a neighbouring country is co-channel with an IMT600 base station in the UK having an elevated directive antenna pointing toward the DTT transmitter. There have been several studies[89] which have examined this interference mechanism using different modelling and simulation approaches. Depending on the I/N protection criteria, % time of interference, land/sea paths, and of course the basic DTT and base station parameters, coordination distances of between 150km and 400km have been cited. These coordination distances also assume there are no mitigation measures implemented.

Inspection of public domain sources of European DTT networks reveal that the Republic of Ireland only operates two multiplexes using DVB-T for its DTT network. Assuming that the Republic of Ireland is not planning to increase the number of its multiplexes, the Republic of Ireland is in a potentially stronger position than the UK to repack its multiplexes and take advantage of a spectrum dividend for IMT600 FDD. Analysis of the main broadcast transmitters in the Republic of Ireland indicates that all the higher power UHF channels which would be co-channelled with IMT600 FDD uplink (UHF Channels 45 to 48) are generally transmitted from DTT sites in the West of the Republic of Ireland, with the exception of the Clermont Cairn DTT site which uses Channel 45 in the very northeast of the Republic of Ireland which serves both the Republic of Ireland and Northern Ireland. These Republic of Ireland DTT sites would impact Northern Ireland's ability to adopt IMT600, assuming that the Republic of Ireland doesn't wish to pursue an IMT600 route. It does appear that Clermont Cairn also employs significant azimuthal filtering of up to 20dB directed at England, which will mean less impact into northern England and Wales. Regardless of how the Republic of Ireland chooses the future of its UHF spectrum, the fact there are only two multiplexes, and potentially only one channel on one DTT transmitter (Clermont Cairn) which would ideally need a different channel provides scope for a relatively straightforward amendment of bilateral agreements between the UK and Ireland. Of course, if the UK wants to pursue an IMT600 dividend but the Republic of Ireland does not want to adopt IMT600, then the UK MNO's can adopt a number of mitigation measures which are described below.

[89] https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-BT.2337-1-2018-PDF-E.pdf

Exhibit 40: Broadcast and mobile split in 470-694 MHz scenario – DTT sites in Republic of Ireland and France occupying channels 45 to 48 being co-channel with IMT600 FDD uplink sub-band



Source: fmscan.org and Coleago Consulting

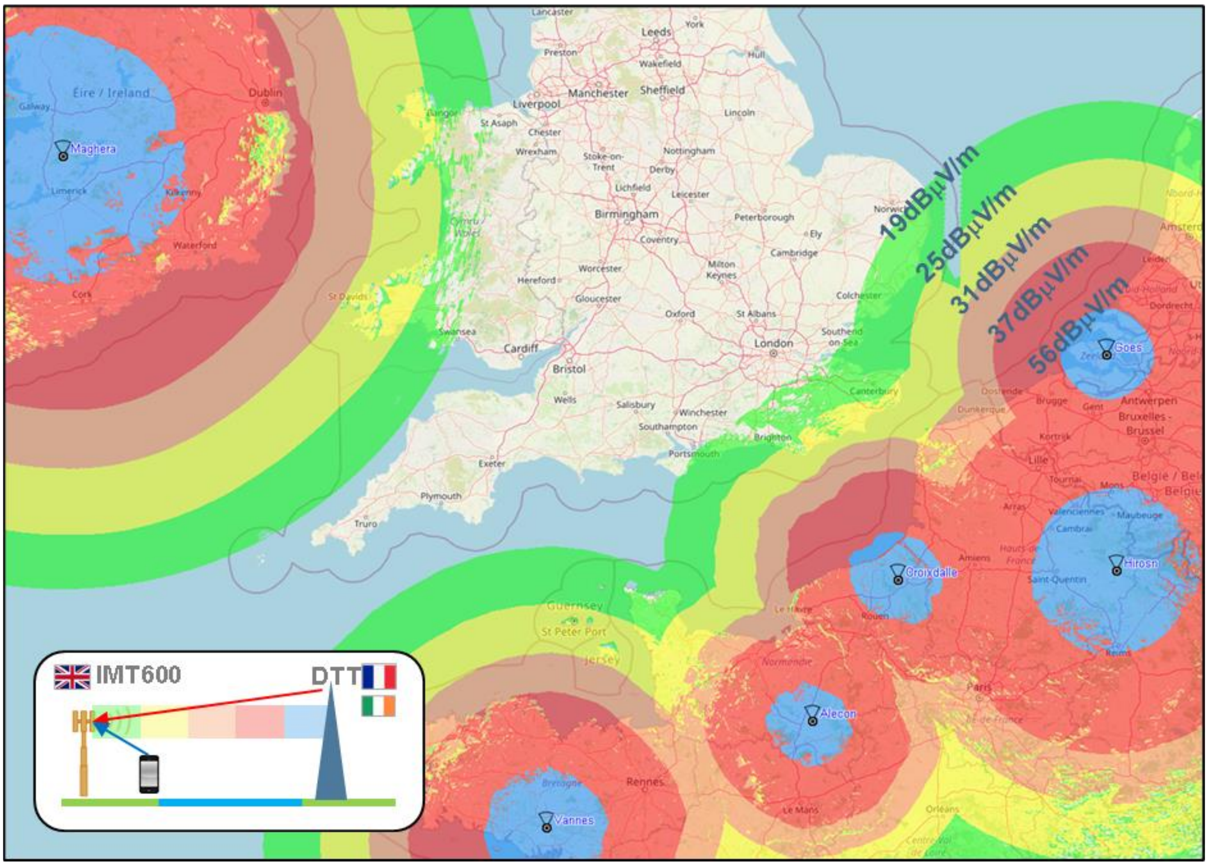
Inspection of the Netherlands DTT networks reveals that most DTT sites are Medium Power, Medium Tower (MPMT) with no DTT transmitter exceeding 20kW ERP power, with most coastal DTT sites also employing azimuthal radiation patterns with attenuation towards the UK. Our estimates of DTT field strengths in the UK from the Netherlands indicate that UK IMT600 FDD networks should not be impacted by Dutch DTT transmissions, so long as the Netherlands does not change to a High-Power/High-Tower model which would be very unlikely.

The Belgium DTT networks currently use only two national multiplexes and only occupy four UHF channels through extensive use of SFNs. The four DTT channels in use by Belgium are however above UHF channel 40 which would impact IMT600 FDD networks in the UK. The Belgian broadcaster RTBF has indicated that it plans to switch off its DTT network by 2027[90], which would take Belgium to two multiplexes consuming only two UHF channels. Given that Belgium is expected to eventually need only two UHF channels but may have been allocated more UHF channel allotments, this suggests that there may be some scope at least for further exploration in the adjustment of bilateral agreements. This is something that should be studied further as a recommendation.

Analysis of the French DTT network reveals a more extensive use of High-Power/High-Tower DTT broadcast sites. The French DTT network has similarities to the UK DTT network in that there are six national multiplexes. Using the same methodology and propagation modelling as used for the coordination studies in ITU-R Report 2337-1, the following plot depicts the estimated field strength from French DTT broadcast sites with Channel 48 using published ERP values of French DTT transmitters together with nominal omni-directional patterns for simplicity. The 19dBµV/m contour represents the case where there would be a -6dB I/N threshold exceeded for 1% of the time at an IMT600 base station uplink receiver using a directive panel antenna at 30m height and directed towards France. The 25dBµV/m contour represents a relaxation of the I/N to 0dB. The 31dBµV/m contour represents a -6dB I/N threshold when using a base station antenna with a polarisation orthogonal (V-Polarised) to the French DTT sites (DTT from France is horizontally polarised), and the 37dBµV/m contour represents a 0dB I/N with orthogonal polarised antenna at the base station.

[90] https://www.broadbandtvnews.com/2022/01/05/rtbf-wants-to-switch-off-fm-and-dvb-t /

Exhibit 41: Estimated field strength values exceeded for 1% of the time from French and Irish DTT sites using CH48



Source: Coleago Consulting

The plot above was calibrated against previous studies from the ITU as a benchmark, which had assumed a 30m base station antenna height and a nominal 3° antenna down-tilt. Most base stations in the UK are however closer to 20m in height which should afford around 6dB additional protection. Furthermore, a 600 MHz base station antenna of 2.4m length tilted at 6° will provide a further 3-4dB of protection. If the mitigation techniques of using vertically polarised antennas, accepting a 0dB I/N threshold, assuming 20m base stations, and additional tilt then almost all of the UK IMT600 base station sites in South-East England could be reasonably well protected. During our interviews we asked operator stakeholders their views on using IMT spectrum which might be allocated as Secondary (and therefore not able to claim protection from interference from DTT), or accepting some interference risk, some respondents stated that co-existence and managing interference is something that they are comfortable with and would be able to accept. We in fact recommend that stakeholders such as Ofcom and the Mobile Operators should consider engaging in making long term measurements of DTT field strengths from French DTT stations along the South Coast of England, Western Wales, and elsewhere. These measurements can be made public and to help inform operators of the potential interference risks and hence allow them to better value the 600 MHz spectrum if this was to be made available, either as an interim 2x20 MHz assignment, as proposed in this study, and/or as the full 2x35 MHz IMT600 band plan.

Other regulators have carried out similar measurement studies ahead of spectrum auctions. For example, CST in Saudi Arabia performed measurements at various coastal locations in the Kingdom of DTT Broadcasts from neighbouring countries in the 600 MHz and 700 MHz bands, ahead of their auction of IMT600 and iMT700 spectrum[91]. Saudi Arabia however is in a region which is prone to high levels of tropospheric propagation which can carry distant UHF signals hundreds of kilometres.

There are also innovative third-party solutions which specialise in removal of interference through adaptive processing of baseband signals accessed via the digital Common Public Radio Interface (CPRI). Such adaptive solutions have been used in several real-world deployments and have shown to provide over 20dB rejection of TV broadcast interference in the

[91] https://www.cst.gov.sa/en/ntn/Documents/doc2.pdf

IMT700 MHz bands. These additional mitigation measures could be used at IMT600 sites which may be more exposed to DTT interference such sites along elevated portions of the south and south-eastern coastlines.

Although this may not be needed it may also be worth exploring the idea of intentionally disabling the IMT600 uplink. In this way, the IMT600 FDD is effectively configured to perform as an SDL component, at least until all countries can be harmonised across Europe. Such a technique could be used as a more general coordination enablement tool, to allow different countries across Europe to adopt IMT600 at different times for example. This is an area recommended for further investigation. This technique has been used in many parts of the world where neighbouring countries do not have harmonised band plans. For example, this Uplink disabling technique has been used in 2600 MHz FDD (Band 7) when a neighbouring country is using the spectrum for 2600 MHz TDD (Band 41).

7.8.3 UK IMT600 Uplink co-existence with International DTT

If the UK adopted IMT600, then Mobile Operators in the UK must ensure that there would be no harmful interference at within France, Ireland, The Netherlands and Belgium. Co-existence studies carried out as inputs into WRC-23[92] and referenced in the RSPG opinion on the future use of the UHF band beyond 2030[93] indicate that separation distances of between 50 and 200km may be needed between IMT600 base stations (ranging from single base station to 378 base station cluster) and a DTT service area in a neighbouring country. These studies assumed Base Station heights of 30m using 3^{o} beam tilt, and a threshold ranging from 0dB and -19dB i/N for 50% of the time at the DTT Receiver.

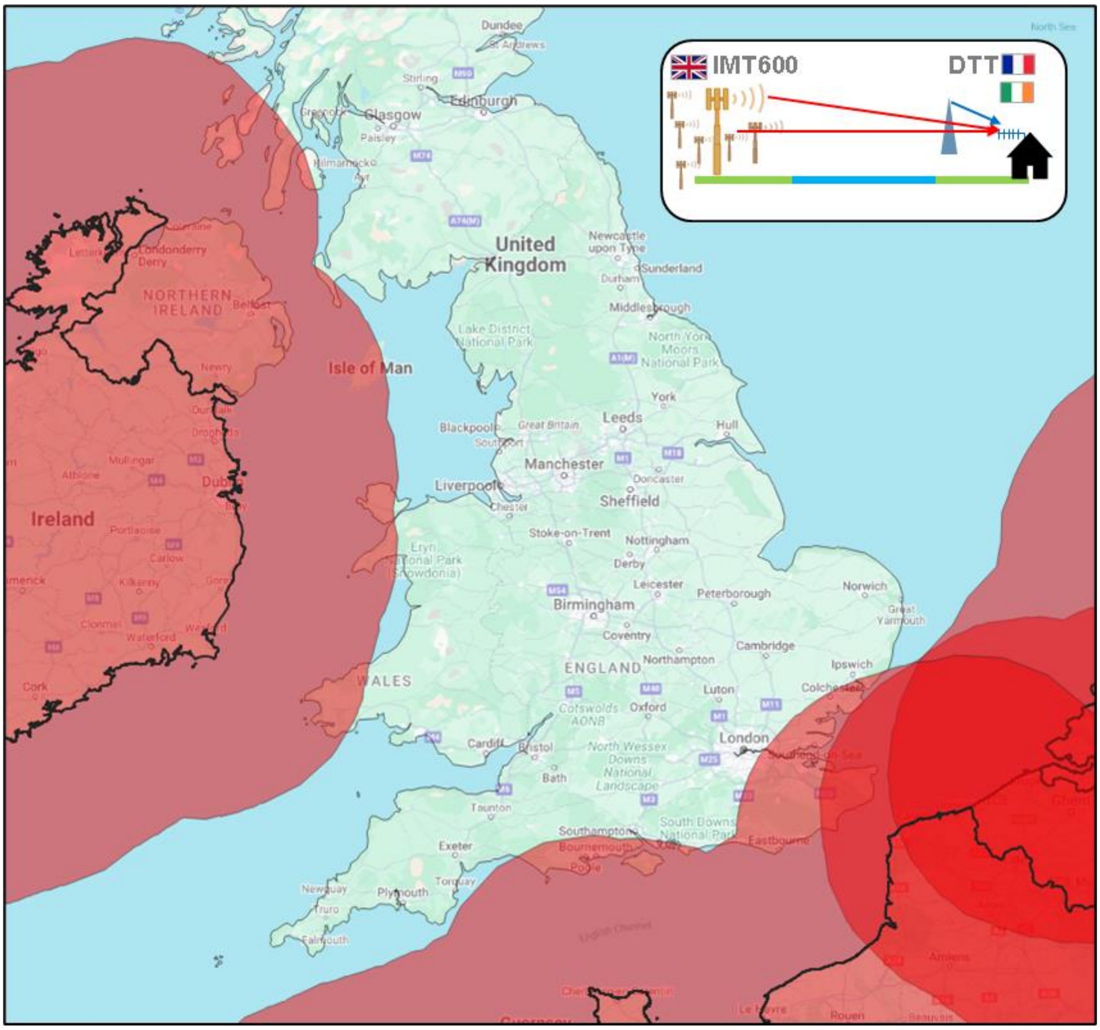
In the UK, Base Station antenna heights are closer to 20m rather than 30m, and we use an I/N protection ratio of -12.8dB and aggregate interference from 378 base stations then we estimate the coordination distance to be around 125km. This distance contour is shown on the map below from France, Ireland, Belgium and The Netherlands. In reality there wouldn't be 378 base stations causing aggregate interference from western Wales or southwestern Scotland, and as such the contour from Ireland could be much less than 125km, and only Northern Ireland is affected. This map suggests there could be some interference risk to DTT from base stations from the very Southeastern part, and from along the very southern coast of England.

Mitigation measures include using additional down tilt, lowering power, directing sectors away from France and Belgium, and using at least two spatially separated V-Polarised base station antennas. We consider that using one of more of these mitigation approaches would adequately mitigate interference risks.

92 https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-BT.2337-1-2018-PDF-E.pdf

93 https://radio-spectrum-policy-group.ec.europa.eu/system/files/2023-10/RSPG23-035final-RSPG_Opinion_on_UHF_beyond_2030.pdf

Exhibit 42: Estimated areas where there may be some interference risk from UK IMT600 to DTT



Source: Coleago Consulting

7.9 Device support for 600 MHz

If an IMT600 band plan was created for the UK, then this would allow mobile operators to deploy the spectrum and provide additional capacity aimed at rural areas and deep indoor penetration in urban areas. However, the usable capacity from a network is only possible if mobile devices also support the band.

All devices sold in the UK market to date support one or many of the existing licenced spectrum bands. Bands such as 800 MHz, 900 MHz, 1800 MHz, and 2100 MHz are very popular, and almost all devices will support these bands. Spectrum bands such as 700 MHz and 3500 MHz have been more recently deployed for 5G services and there is a large growing proportion of devices supporting these bands.

However, to date devices supporting 600 MHz for 4G (Band 71) or 5G (Band n71) are not as common in the UK. This is because device manufacturers such as Apple or Samsung tend to offer the same device model in different regions of the world but supporting different combinations of spectrum bands. For example, the flagship Apple iPhone 16 Pro Max is shipped as four versions: one for the US market, one for the Middle East/Canada/Mexico market, one for the China market and one for everywhere else termed the international version. The versions for the USA, and Middle East/Canada/Mexico all support Band 71/n71 for IMT600. The international and China variants do not support 600 MHz[94]. This means that if 600 MHz was launched in the UK, Apple iPhone 16 Pro Max devices sold in the UK would not be able to make use of then

[94] https://www.gsmarena.com/apple_iphone_16_pro_max-13123.php

band. Samsung tends to have two variants: USA and International for everywhere outside of the US. There are however many smaller device vendors such as Google and Xiaomi who do have devices which do support 600 MHz as some vendors have chosen to provide one variant aimed at a world market rather than regional markets. We have not been able to determine the proportion of devices in the UK which support 600 MHz. This data would be considered confidential by the operators. However, our analysis of device data from 2023 in other country markets in ITU Region 1 indicate that there are device populations supporting 600 MHz of between 10%-30% but these are in countries where Apple and Samsung devices are less prevalent.

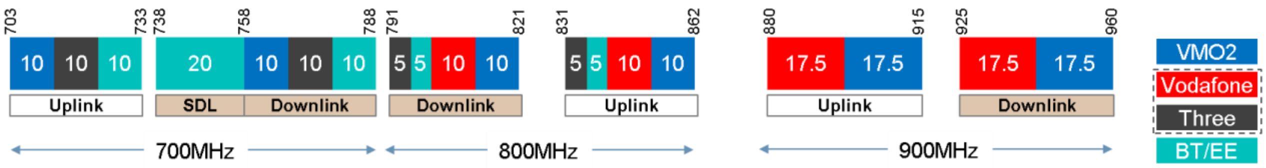
If a region like Europe decided to adopt 600 MHz, then it would be reasonable to expect device manufacturers using regional variant model to start supporting the band. This is what has happened in the Middle East with Saudi Arabia and soon other administrations in the region assigning 600 MHz. If the UK went with 600 MHz alone and separate from Europe or ahead of a European decision for 600 MHz, then the Middle East/Canada/Mexico variants of the Apple iPhone family would perhaps become the Middle East/Canada/Mexico/UK variant and would need to be introduced. It can take a number of years for band support across devices to become significant and relies on device refresh cycles. Of note, the UK is planning to auction mmWave spectrum later in 2025 and a similar device limitation exists in that most devices in the UK at present are unable to support mmWave and would require future devices to be sold and introduced which do support mmWave.

8. Optimising low band assignments

8.1 Existing mobile operator low band spectrum assignments

The exhibit below depicts the current assignments of sub-1 GHz spectrum in the UK. The most recent change in these assignments was the defragmentation within the 900 MHz band, since our previous report[95]. Historically, the 900 MHz band had interleaved assignments between Vodafone and VMO2. The recent defragmentation is an example of how the 900 MHz band has been optimised for spectrum efficiency. Vodafone and VMO2 can now deploy larger bandwidth channels in the future, such as LTE15 or NR15 channels, and can better mitigate against Passive Intermodulation (PIM) interference risks. VMO2 are planning to be switch off 3G services in the 900 MHz band by the end of 2025[96]. Both Vodafone and VMO2 can continue to provide 2G services in the remaining spectrum which would be a minimum of 2x2.5 MHz each, until the latest of 2033 when 2G services are planned to be switched off[97].

Exhibit 43: UK mobile operator spectrum allocation across 700, 800, and 900 MHz bands



Source: Coleago Consulting

All UK operators have allocations which are across three distinct low band allocations. This assumes that Vodafone and Three merge as a new operator entity without spectrum divestments. The operators have arrived at these assignments due to historic evolution of the sub-1 GHz spectrum bands. The 900 MHz band was the original cellular band from the mid 1980's composed of a 2 x 25 MHz plan, which was extended to a 2 x 35 MHz plan during the early 2000s, and then an 800 MHz spectrum auction in 2013 was followed by a 700 MHz auction in 2021.

There are several inherent spectrum inefficiencies with the current assignments. Fragmented assignments are the cause of many of these inefficiencies. These include:

- Need for multiple single band radios, or for multi-band radios at sites
- Trunking efficiencies will be lower
- Need to rely upon Carrier Aggregation to improve QoS in areas served only by low band
- Passive Intermodulation (PIM) interference risks when combining bands
- Practically having to limit MIMO order to 2x2 using 2T2R radios on some services due to PIM risks

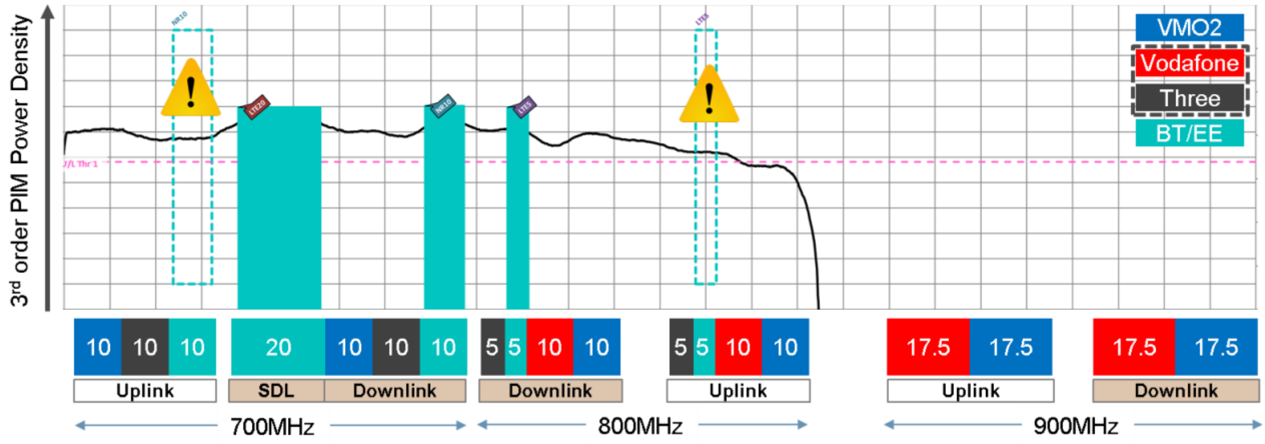
To illustrate some of the inefficiencies, the exhibit below depicts the scenario where EE combine all their low band spectrum using the same multi-band radio hardware and base station antenna array. Due to non-linearities in the RF chain (which always exist) there will be low-level spectral products generated from inter-modulation of the transmissions. If this spectral energy falls into one of more of the Uplink bands there is a risk of interference, since Downlink and Uplink paths are duplexed onto the same antenna ports. To mitigate against this PIM interference risk, the use of separate radio paths and antenna arrays are required. This means there would be less opportunity to take advantage of higher order MIMO configurations, such as 4 x 2 and 4 x 4 MIMO on downlink, in one or more bands at a future date, since additional antenna arrays needed for higher order MIMO are being used instead for PIM interference avoidance. A full discussion of MIMO schemes however is beyond the scope of this project.

[95] https://www.techuk.org/resource/uk-spf-reports-a-key-insight-into-future-spectrum-policy.html

[96] https://news.virginmediao2.co.uk/virgin-media-o2-to-begin-3g-switch-off-in-durham-in-april/

[97] https://www.ofcom.org.uk/phones-and-broadband/coverage-and-speeds/3g-switch-off

Exhibit 44: Example of PIM interference risk when combining certain multiple low band spectrum combinations



Source: Coleago Consulting

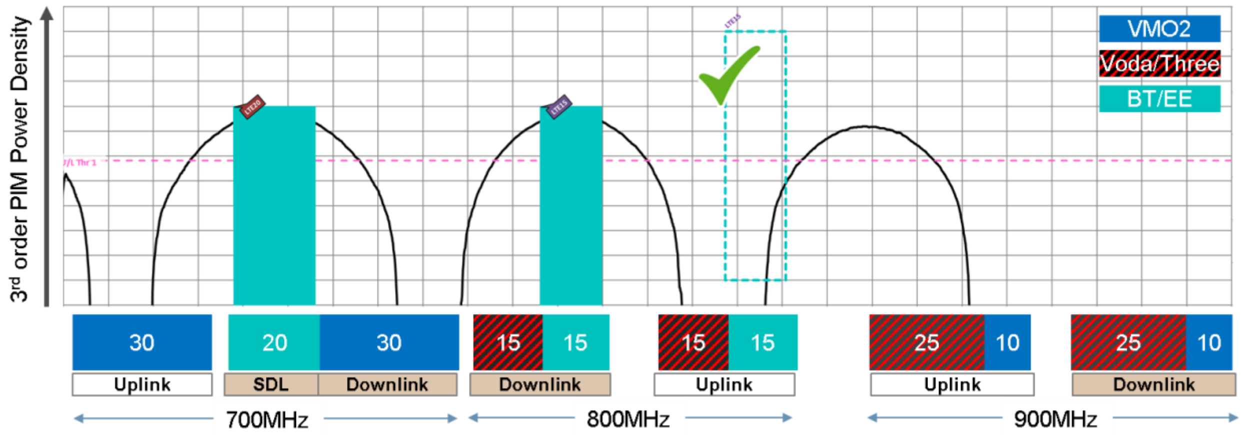
Although we show the PIM risk associated with EE in the above exhibit, there are very similar PIM risks associated with combining all of VMO2's assignments into a common antenna array, or with combining all of Vodafone/Three spectrum assignments into a common antenna array.

8.2 Optimising mobile operator low band spectrum assignments

Band defragmentation in principle would solve many of these inefficiencies, but because there have been different mobile devices supporting different bands including 4G and 5G support, there can be some value difference between the bands. However, as 5G adoption continues to grow and as more devices can support all low bands, the value of the bands becomes more equitable. It is reasonable to assume all three spectrum bands at 700, 800 and 900 MHz could be viewed with more similar values in the future. Perhaps by the 2030s there may be more desire and appetite for operators to engage in a spectrum defragmentation process across the 700, 800 and 900 MHz bands, as opposed to simply acquiring additional low band spectrum in a future 600 MHz allocation. It would not make sense to propose spectrum band defragmentation now due to the current variations in band support across mobile devices. There are dozens of possible defragmentation outcomes, and these will also be influenced by any existing Multi-Operator Radio Access Sharing (MORAN) agreements such as those in place with Vodafone and VMO2.

The exhibit below depicts an example outcome of a future low band spectrum defragmentation process perhaps achieved via spectrum trading mechanisms. In this example, we show the PIM interference risk associated with EE's spectrum assignment is now much reduced. In fact, the spectrum assignments can be shown to reduce harmful PIM interference for all operators which in turn allows deployment of higher-order MIMO such as 4x2 and 4x4 MIMO from more locations. When also accounting for trunking efficiencies and carrier aggregation factors, we estimate that there could be over 25% gains in spectral efficiency for each operator with this spectrum plan. Additionally, there can also be a useful increase in downlink coverage owing to precoder based beamforming gains when using two closely spaced dual cross-polar antenna arrays, which could also be of value for further enhancing rural area coverage and for increasing in-building penetration.

Exhibit 45: Example defragmented MNO spectrum allocation across 700, 800, and 900 MHz bands



Source: Coleago Consulting

Such defragmentation may however benefit one operator more than another, which should be reflected in any spectrum trading. Additionally, operators may have already factored such inefficiency and competitive aspects into their network roadmaps. As such there is also the real possibility that spectrum does not get defragmented due to competitive tension and ultimately remains with some inefficiencies. An area of future study might be how market mechanisms could be optimised to facilitate and promote spectrum efficiency at low band.

It should be noted that assigning one band for one operator may appear to be an optimal de-fragmentation, but this can become sub-optimal since a single operator running the entire 800 MHz or 900 MHz band can suffer from self-interference risk from PIM.

Studies on re-farming the entire 694-960 MHz band to arrive at completely new band plans have also been proposed and studied[98]. Such new band plans essentially explore the capacity gains if the current 700, 800 and 900 MHz band plans could be consolidated, removing guard-bands and reducing duplex gaps, and even includes a conversion of the whole band to TDD. The practical challenge is how such new bands could ever be introduced, as it would require global efforts, and a lengthy transitional period which may have to endure lower spectral efficiencies in the band before reaping the greater spectral efficiencies of any new band plan across 694-960 MHz. As such, we do not consider these as practical options for a 2030s timeframe at least.

[98] The defragmentation dividend, A more efficient use of the UHF band White paper on behalf of Digital UK, Nov 2017

9. Potential areas of further research

To identify which scenario will predominate we believe that the following topics will need further study:

- Full cost/benefit analysis involving all major stakeholders for future DTT Cases 1 to 5 (and other likely variations)
- 733-758 MHz for PMSE Temporary relief – change to BT/EE licence, spectrum management, PMSE device support for 700 MHz, interference in duplex gap to PMSE devices – how much of the 25 MHz can be used by PMSE?
- DTG to explore existing TV Set Adjacent Channel rejection and blocking performance from Mobile Devices transmitting on their Uplink adjacent to a TV set receiving DTT on Channel 46
- PMSE/IMT geographic and time sharing – spectrum management approaches, what are safe distance for indoor PMSE, outdoor PMSE, does this change with WMAS and needs less interference margin?
- Cost/benefit analysis for potential end-user PMSE equipment upgrade/swap – Theatres, studios and large festivals all invested using WMAS in the coming years?
- Study into market mechanisms to facilitate optimum low band assignments from 2030 onwards including private networks. How can the spectrum be best used?
- Study of co-channel interference risk to IMT600 Uplink from DTT stations located in France, Ireland, Netherlands, and Belgium. Conduct measurements and monitoring of non-UK DTT transmissions and analyse results for interference risks into IMT600 FDD Uplink.
- Analysis of IMT600 FDD uplink interference mitigation methods so UK can be best prepared for early IMT600
- Launch consultation to industry of introducing 2 x 20 MHz IMT600 plan from 2027-2030 timeframe. Views on current Secondary allocation or wait >2031 for co-primary allocation or wait >2035 for possible primary and a full 2 x 35 MHz release?
- Explore Republic of Ireland's appetite and views for IMT600 given that Ireland only runs a two Multiplex layer DTT network, and whether it makes sense to engage in joint planning studies?
- Study and modelling of future 960-1154 MHz band use with LDACS and Link-16. How will this impact PMSE spectrum availability?
- Full design of DTT network for 600 MHz clearance to better understand likely re-engineering effort and costs for antenna replacements, need for temporary transmitters, and coordination with neighbouring countries
- Study into the potential future use of 470 to 614 MHz spectrum in the UK in the event of Case 5 becoming a reality i.e. the IPTV scenario

Annex 1: Literature search

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Annex 2: Stakeholder Interviews

In the preparation of this report, we have conducted a wide range of interviews with many of the key the stakeholders involved in the usage of the UHF spectrum and all interviews were conducted under Chatham House rules. In total 17 stakeholder organisations were interviewed including:

- Ofcom
- DSIT
- DCMS
- Everyone TV
- BBC
- ITV
- DMSL
- BT/EE
- Virgin Media O2
- Vodafone
- Nokia
- BEIRG
- DTG
- DTG-PMSE Group
- LG Electronics
- Sony
- Rohde & Schwarz

Annex 3: Glossary

3GPP	3rd Generation Partnership Project
4K	Ultra-High-Definition TV standard ~4,000 horizontal pixel resolution
AI	Artificial Intelligence (i.e., machine learning).
ADSL	Asymmetric Digital Subscriber Line
APWPT	Association of Professional Wireless Production Technologies
API	Application Protocol Interface
APT	Asia Pacific Telecommunity
AR	Augmented Reality. Also see VR.
ARIMA	Auto Regressive Integrated Moving Average
ARPU	Average Revenue per Unit.
AUPU	Average Usage per Unit or per User
AV	Audio Visual
AVOD	Advertising-based Video-on-Demand/Advertising-financed Video on Demand
BBU	Baseband Unit.
BEM	Band Edge Mask
BNE	Broadcast Networks Europe
BVOD	Broadcaster Video-on-Demand
CA	Carrier Aggregation
CAGR	Compound Annual Growth Rate
Capex	Capital Expenditure (i.e. investments)
CEPT-ECC	Electronic Communications Committee of the European Conference of Postal and Telecommunications Administrations
C-PMSE	Cognitive Programme Making and Special Events
COTS	Commercial Off-The-Shelf.
CPRI	Common Public Radio Interface
CU	Central Unit.
DL	Downlink
DSL	Digital Subscriber Line
DSS	Dynamic Spectrum Sharing (allows bandwidth to be allocated between different technologies such as 4G and 5G).
DTT	Digital Terrestrial Television
DU	Distributed Unit(s).

DVB-HB	Digital Video Broadcasting - Home Broadcasting
DVB-I Digital video broadcasting - internet	Digital Video Broadcasting - Internet
DVB-T	Digital Video Broadcasting – Terrestrial
DVB-T2	Digital Video Broadcasting - Terrestrial 2nd generation
EB	Exabyte (also see ZB)
EBITDA	Earnings Before Interest, Tax, Depreciation and Amortisation.
EAO	European Audiovisual Observatory
EBU	European Broadcasting Union
EC	European Commission
EIRP	Effective Isotropic Radiated Power
eMBB	Enhanced Mobile Broadband
eMBMS	Enhanced Multimedia Broadcast Multicast Services
eMTC	Enhanced Machine Type Communications
EPG	Electronic Programme Guide
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex. In FDD mode, half of the bandwidth is allocated to uplink, half to downlink. Hence the notation 2x20 MHz for a 20 MHz 'paired' channel. Also see TDD.
FeMBMS	Further enhanced Multimedia Broadcast Multicast Services
FR1, FR2	Frequency Range 1 (bands below 6GHz) and Frequency Range 2 (millimetre waves).
FTA	Free To Air
FTV	Free-To-View
FVOD	Free Video on Demand
FWA	Fixed Wireless Access.
GE06	Geneva 2006 Conference and Agreement
HbbTV	Hybrid broadcast broadband TV
HD	High Definition
HDR	High Dynamic Range
HDTV	High-Definition Television
HEVC	High Efficiency Video Coding
HFR	High Frame Rate
HPHT	High Power, High Tower
IBB	Integrated Broadcast-Broadband system

IEM	In Ear Monitor
IMT	International Mobile Telecommunications
IoT	Internet of Things: machine-to-machine or “machine-type” communications via the Internet, mediated by fixed and/or wireless networks.
IP	Internet Protocol
IPTV	Internet Protocol Television
ITU	International Telecommunications Union
LLS	Lower Layer Split (in context of open RAN)
LPLT	Low Power, Low Tower
LTE	Long Term Evolution (4G)
M2M	Machine-to-Machine (see IoT)
Mbps or Mbit/s	Megabits per second (a measure of network throughput).
MIMO	Multiple Input / Multiple Output antenna system; e.g. 2T2R (meaning two transmit and 2 receiver antennas on the site), which is the base MIMO configuration for 4G and 5G, also referred to as “order 2” or “2x2” MIMO.
MIP	Mobile Infrastructure Project
mMIMO	Massive MIMO (typically 32x32 or 64x64 order MIMO)
MNO	Mobile Network Operator
MPEG	Motion Pictures Expert Group
MPEG2	Video encoding standard, MPEG2 was the second of several standards developed by the Moving Pictures Expert Group
MPEG4	Video encoding standard, MPEG4 was the fourth of several standards developed by the Moving Pictures Expert Group
MPMT	Medium Power, Medium Tower
NGMN	Next Generation Mobile Alliance
NSA	Non-Stand-Alone
OFDM	Orthogonal Frequency Division Multiplexing
Opex	Operating Expenditures (recurring or ‘running’ costs)
O-RAN	Open RAN Alliance (not to be confused with “Open RAN”)
OTT	Over-The-Top
PB	Petabyte (also see ZB)
PC	Personal Computer
PIM	Passive Inter-Modulation (intermodulation distortion caused by passive components)
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief.
PSB	Public Service Broadcasting

PSM	Public Service Media
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network. Includes radio sites and backhaul transmission (but not the core network).
RF	Radio Frequency (e.g. RF unit)
RIC	RAN Intelligent Controller
ROIC	Return On Invested Capital
ROM	Receive Only Mode
RRU	Remote Radio Unit.
SA	Stand-Alone.
SD	Standard Definition
SDR	Software Defined Radio.
SLA	Service Level Agreement
SMO	Shared Rural Network
SRN	Service Management & Orchestration
SVOD	Subscription Video on Demand
TB	Terabyte (also see ZB)
TDD	Time Division Duplex. Also see FDD. Spectrum in TDD mode allows for asymmetric allocation of uplink and downlink resources, yielding greater overall spectral efficiency.
TIP	Telecom Infra Project
TV	Television
TVOD	Transactional Video on Demand
UE	User Equipment
UHD	Ultra-High-Definition TV standard ~4,000 horizontal pixel resolution
UHF	Ultra-High Frequency (300 MHz to 3GHz)
UL	Uplink
UP	User Plane (in context of network slicing)
uRLLC	Ultra-Reliable Low Latency Communications.
VHF	Very High Frequency (30 MHz to 300 MHz)
VOD	Video On Demand
VR	Virtual Reality. Also see AR
VVC	Versatile Video Coding
WACC	Weighted Average Cost of Capital.
WCG	Wide Colour Gamut
WMAS	Wireless Multichannel Audio Systems

WRC	World Radio Conference
ZB	Zettabyte, equivalent to 1000 EB (Exabytes), 1 million PB (Petabytes), 1 billion TB (Terabytes) and 1 trillion GBytes.

