The future use of UHF spectrum in ITU Region 1

May 2021

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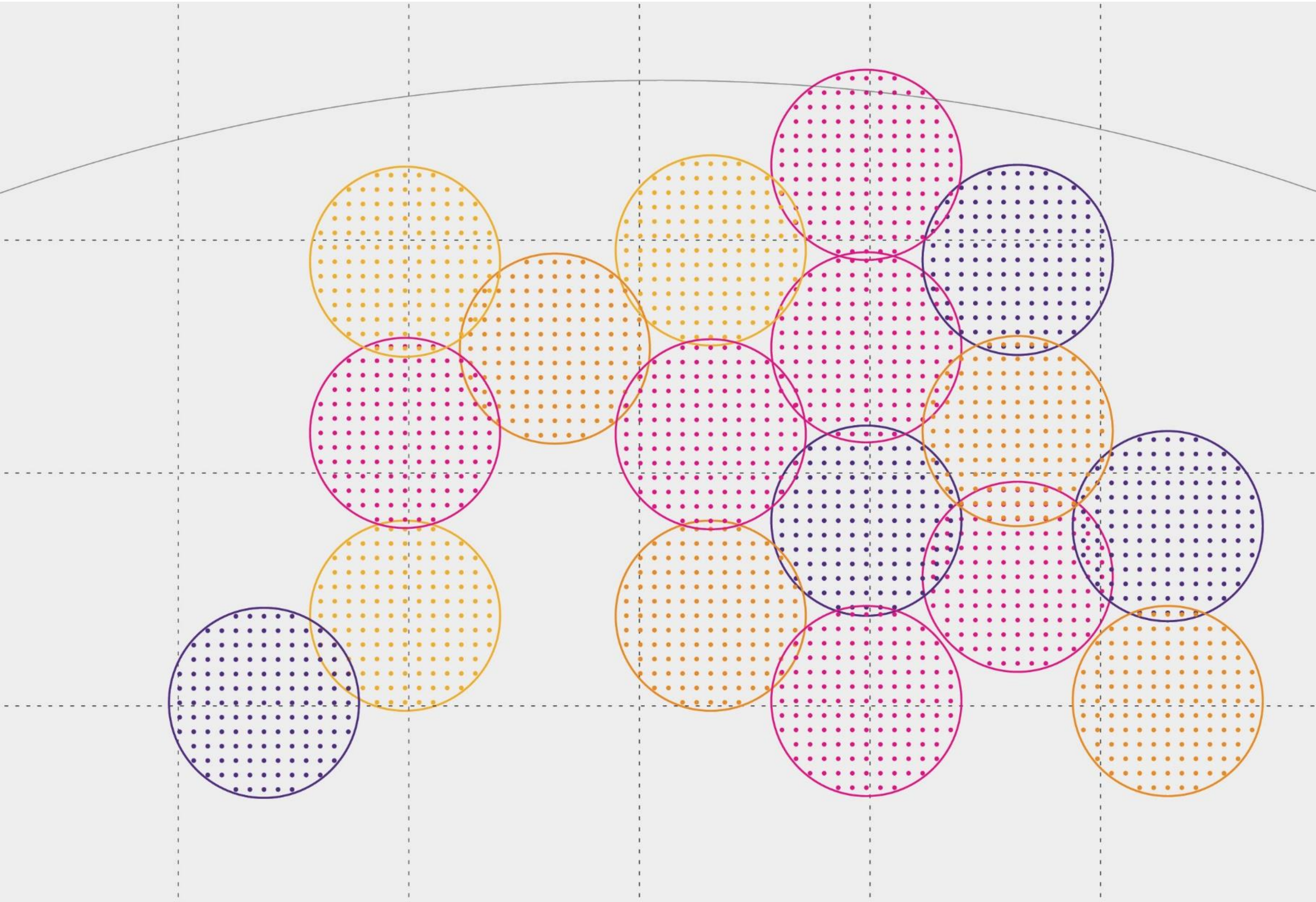

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About Plum

Plum offers strategy, policy and regulatory advice on telecoms, spectrum, online and audio-visual media issues. We draw on economics and engineering, our knowledge of the sector and our clients' understanding and perspective to shape and respond to convergence.

About this study

This independent study, commissioned by the GSA, considers the use of UHF spectrum generally, but in particular the sub-700 MHz band, in a number of different services, focussing on its use in ITU Region 1. The study sets out the potential use for UHF spectrum in mobile, broadcasting, PMSE, PPDR and radioastronomy, and considers how these demands vary by geography. We conclude with consideration of how a more regional approach to spectrum assignment may lead to significant benefits.

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Summary

This independent study examines the current and future use of the UHF band in general, but in particular the portion of this band between 470 MHz and 694 MHz. Historically this spectrum has been allocated and used by television broadcasting, with secondary users of PMSE equipment in the white spaces created by the need for non-overlapping transmissions (and a small reservation for use by radio astronomy). However, with changing demand from mobile services and broadcast viewing habits, this paper considers whether there is a need to revisit this allocation.

Mobile broadband growth requires more low-band spectrum

First, we look at the use of sub-1 GHz UHF spectrum by mobile broadband services. There has been a very large increase in the use of mobile broadband over the past decade, across rural and urban areas, and in both developing and developed countries. Consumers and enterprises alike are using connections for a wide variety of services, and many now rely on high quality broadband for work, productivity, home keeping, and entertainment. A key driver of mobile data is video, representing over three quarters of all traffic, and as screens improve in resolution and consumers increasingly acquire VR and AR equipment, demand for mobile data will accelerate further.

Against this large increase in demand, many regions, particularly deep rural areas, do not have sufficient capacity on their mobile networks so as to provide high performance connections, or have networks and technology that is not capable of delivering these more demanding services – and the economics of networks ensure that operators find it challenging to justify further investment in these areas: typically, investment into additional sites is economically very challenging and faces acceptance issues and regulatory hurdles. This threatens to open a new type of digital divide, where those in urban areas are able to access services that rural inhabitants are excluded from.

The only way to provide these high-quality services in deep rural areas is through greater use of sub-1 GHz UHF spectrum, which will provide network operators with the ability to dedicate further bandwidth on existing site infrastructure to 5G or future mobile technologies. This will not only benefit deep rural areas through the availability of new technologies – although the benefits in those areas are very large by themselves – but it will also benefit those on transport routes and the development of connected vehicles. It will help with economic wellbeing and with societal targets of inclusion and equality, as shown in a number of emerging markets.

DTT usage in UHF is declining

As stated above, the UHF band between 470 MHz and 694 MHz is currently allocated to television broadcasting. However, the use of this technology is decreasing over time. In response to an ITU questionnaire on the use of DTT, some countries[1] responded that less than 224 MHz are being used for this service and so less than this amount would be needed in future. At the same time, while the majority of respondents to the questionnaire indicated that 224 MHz was needed, further analysis shows that there is little use of DTT in many of those countries – for example, in Belgium there is only one broadcasting group offering channels using one multiplex.

While some countries use many multiplexes of DTT to serve large amounts of channels, others have reduced this down to a single multiplex or even switched off DTT entirely. Further, the share of population reached by

[1] Specifically Egypt, Finland, Israel, Kuwait, Saudi Arabia, Slovenia and the UAE.

DTT varies hugely from over 50% down to low single digit percentage figures, even in countries with substantial DTT offerings.

Our research also shows that most broadcasters are already adapting their digital strategies and focusing resources towards developing their online media players and service offerings to introduce more interactive features, personalisation on-demand content and personalised user experiences. In some cases this has also involved reducing the number of linear TV channels or moving them online to cater to the changing audience habits. This is particularly noticeable as the accessibility of IP delivery is improved, with a greater proportion of households having access to high-quality broadband connections. In the face of declining broadcast TV audiences and advertising revenues, DTT distribution, with its fixed cost structure, may become prohibitive particularly for smaller portfolio channels.[2]

The existing use of UHF by other services varies by country

While there are some countries where additional sub-1 GHz UHF spectrum would be available for mobile due to a lack of use by DTT, there are others where it is still used for this service. In some countries DTT remains a vital technology for the distribution of content, and while there are trends away from reliance on DTT (and trends away from linear television viewing overall), it is not feasible to expect broadcasting in those countries to vacate these bands imminently. However, television broadcasting is an inherently inefficient way of using the spectrum due to the need for adjacent areas to use different frequencies[3], and any reduction in the amount of spectrum reserved would be beneficial.

There are other users or potential users of the 470 MHz – 694 MHz UHF band:

- PMSE (programme makers and special events) tends to use parts of the broadcasting spectrum bands in areas where broadcasting is not present; this can require a significant bandwidth of spectrum but in some cases the current bandwidth can be reduced or interference mitigating measures could be introduced. This tends to be very limited in geography, and typically is used in densely populated areas.

- Radio astronomy has been assigned a narrow 5 MHz band in the middle of the 600 MHz allocation, as well as some holdings above and below the key UHF bands.

- PPDR (public protection and disaster relief) can use either dedicated spectrum, effectively running a private mobile network, or be carried over existing networks. While there is currently no use of this spectrum range by PPDR, there are some proposals over the use of this spectrum in the future.

The use of spectrum by each of these services – as with broadcasting – varies by country and location; there are some where there is little demand, and there are some where there is congestion in the band.

A co-primary allocation will enable greater efficiency through increased choice

Currently the spectrum band 470 MHz – 694 MHz is allocated on a primary basis to broadcasting across ITU Region 1. This means that in those countries where terrestrial broadcasting is sparse (even using up to 6 multiplexes), there are large portions of the spectrum in any given location which are unused. Following co-primary mobile allocations of 800 MHz in WRC-07 and 700 MHz in WRC-12/15 in addition to the retained

[2] For example, in Germany public broadcasters ARD and ZDF closed down linear TV channels EinsPlus and ZDFkultur in 2016 as part of the formation of the online youth content network Funk. In France, France Televisions has launched a new digital service Okoo aimed at children aged 3-12, with a view to shutting down the France 4 channel. In Denmark, Danmarks Radio has moved DR3 and DR Ultra to its DRTV streaming service while shutting down DR K).

[3] There is a potential way of reducing this inefficiency, using single frequency networks (SFNs) but this means there is no possibility of regional broadcasting and there are technical challenges over timing of broadcasts and the need for additional bandwidth for error correction.

primary broadcast allocation, both bands had been cleared from broadcast and re-purposed for mobile services Region-wide.

A sole primary allocation of the 470 MHz – 694 MHz band to mobile services is not realistic: there would be a number of countries forced to rearrange their entire broadcasting industry, reducing the number of channels broadcast or investing in large amounts of consumer equipment for cable, satellite, or broadband distribution.

Instead, this paper recommends that the spectrum should be allocated on a co-primary basis, in order to allow national governments and regulators to make decisions over the future use of UHF – such as within the planned UHF review in the European Union. While this would provide additional flexibility to countries seeking more efficient use, it may not result in the need for immediate changes to existing use in other countries or other parts of ITU Region 1. In making these decisions, the public bodies would need to:

- Consider the current and future use of DTT, and examine whether it would be possible to reduce the amount of spectrum used;
- Liaise with neighbouring countries to mitigate any interference caused by different services sharing channels across borders; and
- Examine the ways in which other users of UHF spectrum can be accommodated.

1 Introduction

This independent report from Plum Consulting examines the future use of UHF spectrum, in ITU Region 1 and also worldwide. It draws on information from existing and potential users of the spectrum bands, and examines how benefits from spectrum use may be realised in the future.

1.1 Historic use of UHF

The UHF band is defined by the ITU as spectrum between 300 MHz and 3000 MHz. However, in spectrum management and regulation, the term 'UHF' is frequently used as a shorthand for spectrum between 450 and MHz and 1 GHz – sometimes also called the sub-1 GHz bands. For a number of services these bands are crucial, since they allow for a significant bandwidth to be transmitted over long distances. UHF tends to work on line-of-sight propagation, with signals being blocked by hills (but being able to penetrate buildings), meaning there is certainty over signal strength, allowing detailed network planning.

Historically, UHF spectrum was generally used for television broadcasting, replacing VHF broadcasts across Region 1 during the early 1960s[4]. These allocations were agreed (for the European region) at the ITU Regional Radiocommunication Conference ST61, where spectrum between 470 MHz and 958 MHz was divided into 81 channels. Channel 38 (606 MHz – 614 MHz) was reserved for radio astronomy since most equipment already existed in this band; other uses were permitted on the condition they did not cause interference with television broadcasts. With a large number of channels to use (and limited content to broadcast), countries were able to avoid cross-border interference – and interference between different broadcasting sites within a single country – by spreading the broadcasts across the entire UHF allocation. In practice, most transmissions took place in the lower part of this band (up to 606 MHz), since this allowed for better quality reception on analogue receivers over a wider area.

This distribution meant that at every broadcasting site, there were a significant number of channels not being used. This gave other users an opportunity to run their own private networks or transmissions, such as the use of wireless microphones, without interfering with television broadcasts.

Analogue mobile telephones, first appearing in the early 1980s, used the spectrum bands at 450 MHz[5], with some later variants using the 900 MHz band in certain regions where television broadcasting did not. However, by the early 1990s the introduction of digital mobile telephones, which reduced the cost of networks and massively increased takeup, meant that the 450 MHz band would be unable to cope with traffic, and regulators across Europe and other parts of Region 1 allocated the 900 MHz band to mobile telephony, since this was not being used for analogue broadcasting. With the advent of digital mobile services, this spectrum band was repurposed.

The introduction of digital television allowed for multiple TV channels per 8 MHz RF channel, but during the transition it brought increased demand for UHF spectrum: initially the coexistence of digital and analogue broadcasts meant that sometimes the entire UHF band (up to 858 MHz) was used for broadcasting. However, the plan across Europe (and accepted by the rest of Region 1) was to turn off analogue broadcasts, moving digital broadcasting to the lower part of the UHF bands and freeing up spectrum at 800 MHz for additional capacity on mobile networks. This was agreed in Geneva at RRC-06, where a date of 17 June 2015 was set as the target for switch-over.

[4] Note that some countries continued using VHF spectrum for television broadcasts until the 1990s, but this limited the number of channels and quality that could be broadcast.
[5] This band was shared with long-range paging systems.

The need for additional spectrum in UHF, particularly in sub-1 GHz bands, was driven by a large increase in data traffic on mobile networks. As operators rolled out their 2G networks on 900 MHz and 1800 MHz during the 1990s, there were few cases of capacity constraints, even with the introduction of WAP and GPRS. Regulators initially awarded the 2100 MHz spectrum for 3G services, as it had a wider bandwidth and was cleared, but 3G networks were then forced to have a dense formation of cell sites, increasing costs and meaning that geographic rollout was generally limited to urban areas. Over time, operators reduced the number of 2G connections in the 900 MHz band, meaning they were able to refarm part of this spectrum for rural 3G coverage, but there was a limited capacity available. With the introduction of LTE in 2009, operators had no ability to refarm any sub-1 GHz spectrum, and instead were forced to use part of their 1800 MHz holdings to roll out the first LTE networks.

The aim of the Geneva agreement (GE-06) therefore was to provide certainty to operators that they would be able to access spectrum in the 800 MHz band by (at the latest) 2015, and broadcasters would have a set time to rearrange their use of spectrum. In reality, many countries switched off analogue broadcasts ahead of this point, while others (particularly in Africa) missed the deadline.

By the mid-2010s, there was a generally adopted band plan across Region 1. While some countries were slow to adopt this, and historic licencing meant that some countries were still using alternative spectrum bands such as 850 MHz, the general consensus was as follows.

- Television broadcasts in the band between 470 MHz and 790 MHz,
- LTE services using 790 MHz – 862 MHz (the 800 MHz band) as well as refarmed spectrum in 1800 MHz, and other allocations in 1400 MHz, 2300 MHz and 2600 MHz.
- 3G using 876 MHz – 960 MHz (the 900 MHz band) as well as the initial holdings in 2100 MHz.
- 2G using some remaining spectrum in 900 MHz and 1800 MHz bands.
- Radioastronomy using a reserved band at 606 MHz – 614 MHz.
- PMSE using any unused spectrum in the broadcasting bands.

1.2 Current changes to UHF use

With the advent of 5G, the rise of on-demand viewing, and the introduction of new technologies such as augmented reality, there are increasing demands for spectrum. While significant capacity is required for many of these– meaning that the limited bandwidth available in sub-1 GHz bands is not suitable – for ubiquitous 5G coverage additional UHF spectrum is required.

Predicting this, during the mid-2010s regulators and governments explored the use of the 700 MHz band (694 MHz – 790 MHz) for mobile telecommunications, resulting in an allocation to mobile and identification for IMT in Region 1 at WRC-15.

Following this, television broadcasting has been rearranged to make better use of spectrum below 700 MHz by means of DVB-T2 and more efficient coding, and the 700 MHz band is in the process of being cleared and awarded to mobile operators across Europe and the Middle East. In Africa, some countries awarded the 700 MHz band early due to difficulties with clearing the 800 MHz band, often due to the use of government or military equipment, while others have plans to award it in the future once demand for 5G services is evident.

1.3 Structure of this report

This report has been commissioned to consider the future of the UHF band in ITU Region 1. It looks in turn at various users of the band, considering how demand for their services – and the subsequent demand for spectrum – is changing over time.

- Section 2 examines the use of UHF spectrum by mobile telephony services, including mobile broadband, looking at the growth of Internet services, use of broadband in rural areas, and benefits that can be obtained.
- Section 3 looks at the use of UHF by television broadcasting, reflecting on the current situation in various countries and considering how changes in viewing patterns and distribution paths may affect this demand in the future.
- Section 4 considers other users of UHF spectrum, and how their needs should continue to be met.
- Section 5 analyses how these competing demands for spectrum should be met, including considerations of how interference should be dealt with.

2 The use of UHF spectrum by mobile services

Since the introduction of public mobile phone services in the 1980s, the mobile industry has seen unprecedented growth, with 67% (5.2 billion) of the world's population with a mobile subscription as of Q1 2021.[6] Smartphone adoption, driven by demand for high quality Internet experiences, has been similarly quick; smartphones comprise 69% of total mobile connections as of Q1 2021, up from 41% compared to Q1 2016. The GSMA has estimated that by 2025, 72% of users will access the Internet only via a mobile connection, with the traditional PC (desktop and laptop) connections forming a minority.[7]

This increasing importance of mobile connections for access to the Internet means that a large number of global citizens are reliant on high quality, reliable mobile networks to take part in society. This, coinciding with rising dependence on online services for both social and economic interactions, means that mobile network operators have an important role in enabling an equal society.

Currently, 95% of the world's population has coverage of 3GPP technologies, and momentum in the build-out of 4G (LTE) networks is continuing. Global 4G population coverage at the end of 2020 is estimated by Ericsson to be over 80 percent and is forecast to reach around 95 percent in 2026. There are some 800 commercial 4G networks deployed as of end-2020, and these 4G networks are also evolving to deliver increased network capacity and faster data speeds.[8] Meanwhile, 5G deployment has been gathering pace and 5G is expected to account for 40 percent of all mobile subscriptions by 2026.[9]

2.1 Mobile telecommunications are already using the UHF band

The 900 MHz band was the first widely harmonised mobile band[10] and the foundation for the launch of 2G (GSM) services across Europe and many parts of the world during the 1990s. In parallel the 850 MHz band was adopted by the US and parts of the Americas for AMPS, TDMA and CDMA.[11] As demand for mobile expanded in the subsequent years, various additional frequency bands were identified and allocated to mobile, including 1800 MHz, 2100 MHz and 2600 MHz.

At the 2007 World Radiocommunication Conference (WRC) additional UHF spectrum below 1 GHz was identified for mobile broadband as part of the transition to digital terrestrial television (DTT). Different band plans were adopted across the ITU Regions for the so-called "digital dividend" spectrum. In Region 1 (Europe, Africa, Middle East), this was the 800 MHz (791-821/832-862 MHz); in Region 3 (Asia Pacific) this was the Asia Pacific Telecommunity (APT) 700 MHz band plan (703-748/758-803 MHz). As for Region 2 (Americas), the US had adopted a separate 700 MHz band plan which comprised several sub-bands[12] but aside from Canada and several Caribbean states, the rest of Region 2 adopted the APT 700 MHz plan.

Further developments in the UHF band in the 2010s include the harmonisation of the 700 MHz band in Europe for mobile use following WRC-15, in line with APT band plan and taking account of the 800 MHz band plan.[13] In the US, the broadcast incentive auction which was completed in 2017 resulted in the reallocation of 70 MHz of broadcast TV spectrum in the 600 MHz band for mobile broadband (663-698/617-652 MHz).[14] Canada has also

[6] Unique mobile subscribers as of Q1 2021. Source: GSMA intelligence.
[7] GSMA Intelligence (2018). Global Mobile Trends.
[8] Ericsson (November 2020). Ericsson Mobility Report. Available at https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf
[9] Ericsson (November 2020). Ericsson Mobility Report.
[10] The 862-960 MHz band was allocated for mobile at the 1979 World Administrative Radio Conference (WARC), the predecessor of the World Radiocommunication Conference. The 890-915/935-960 MHz was initially identified for GSM and subsequently extended to 880-915/925-960 MHz.
[11] The 850 MHz comprises 824-849/869-894 MHz.
[12] Including LTE bands 12/17 (699-716/729-746), B13 (746-756/777-787), B29 (717-728).
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1462352514807&uri=CELEX:32016D0687
[14] https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions

followed suit in assigning the 600 MHz for mobile in 2018. Figure 2.1 summarises the current status of the mobile use in the UHF band.

Figure 2.1: Current status of mobile bands in the UHF band (excluding US 700 MHz)[15]

Band (LTE band)	Uplink (MHz)	Downlink (MHz)	Total MHz	ITU Regions	Technologies
900 MHz (B8)	880-915	925-960	2×35	R1, R3, partial R2	2G, 3G, 4G
850 MHz (B5, B26)	814-849	859-894	2×35	R2, partial R3	2G, 3G, 4G
800 MHz (B20)	832-862	791-821	2×5	R1	4G
700 MHz (B28)	703-748	758-803	2×45	R3, R1, partial R2	4G, 5G
700 MHz (B67)	-	738-758	20	Partial R1	4G
600 MHz (B71)	617-652	663-698	2×35	Partial R2	4G, 5G

In every country, mobile operators typically have access to two or three UHF spectrum bands:

- **900 MHz**: In most countries in Regions 1 and 3, 900 MHz was one of the first spectrum bands made available for digital mobile networks, allowing 2G rollout at an affordable cost. In general, this band is still used to support limited 2G traffic, although many operators refarmed significant portions of it for 3G coverage in the mid-2000s. It now supports rural 2G and 3G coverage and capacity, and in many countries operators have refarmed part of this band for use by 4G (LTE) networks.

- **850 MHz**: In Region 2 and some countries in other regions, the 850 MHz band was used for the same purpose. Some regulators reconfigured the 850 MHz band into 800 MHz and 900 MHz lots when renewals were due.

- **800 MHz (EU)**: The 800 MHz band, the first digital dividend, was harmonised for IMT in Region 1 after being cleared of DTT signals (in most cases during the 2010s). Where available, it is used ubiquitously by operators to provide basic coverage of LTE networks. As discussed in Section 2.5.4 below, prior to this award many LTE networks were launched using refarmed 1800 MHz spectrum, which was more costly and uneconomical in rural areas.

- **700 MHz (APT)**: The 700 MHz band was first adopted for IMT in Region 3 as part the digital dividend spectrum. Among Region 3 countries the progress with clearance and assignment is mixed. While many have already assigned the 700 MHz for LTE deployment, awards are yet to be completed in some countries. Meanwhile, this band has also been adopted in many countries across Regions 1 and 2 with many awards completed in the last two years or currently being planned. Here, the 700 MHz band will typically be used for 5G networks, although the limited bandwidth available will limit the speed and quality of service that operators can offer.

- **600 MHz**: In Region 2, the 600 MHz band has been assigned to mobile network operators (MNOs) in the US and Canada, again after clearance from TV broadcasting[16]. Outside Region 2, the band is still used for TV broadcasting in many parts of the world, though it has been generating increasing

[15] Note: 5G NR specifications are already defined for most of these bands.

[16] It should be noted that the 600 MHz reallocation was possible as cable and satellite were the main means through which households accessed TV services in Canada and the US, and usage of over-the-air terrestrial broadcasting is much lower compared with most other countries.

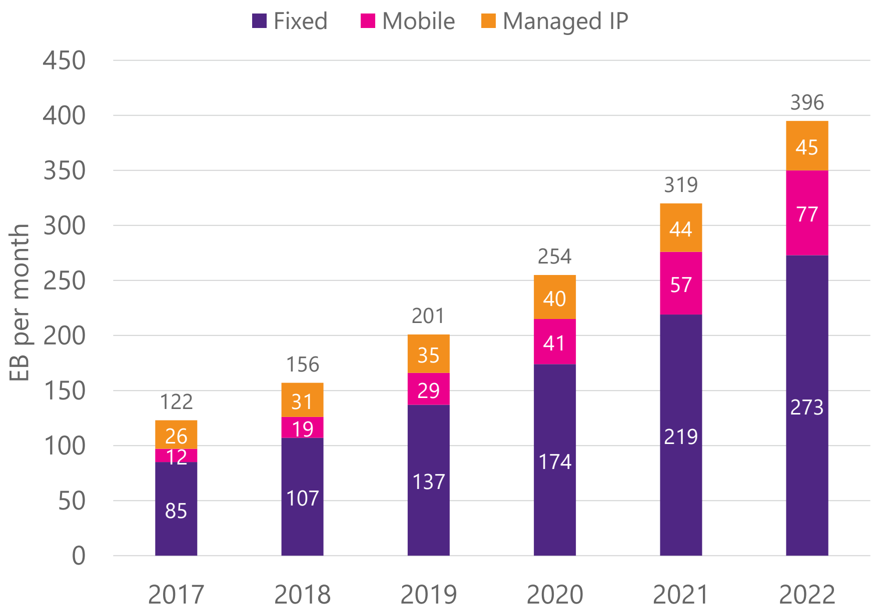
attention. For example, the 600 MHz band has been the subject of recent consultations in Australia[17], Hong Kong[18] and Saudi Arabia.[19]

UHF spectrum continues to be an important resource to quickly and cost efficiently provide mobile services in wide areas and to indoor locations.

2.2 Demand for Internet services is accelerating

The growth in demand for Internet services over the past two decades has been rapid and shows no signs of abating. Based on Cisco estimates the total IP traffic per month was 122 EB in 2017, rising to 396 EB by 2022. Although fixed networks account for the larger of share of total traffic, mobile traffic is growing at a significantly faster rate as shown in Figure 2.2. Over the 2017-2022 period mobile traffic is estimated to increase at a compound annual growth rate (CAGR) of 46% compared to fixed traffic (26%).

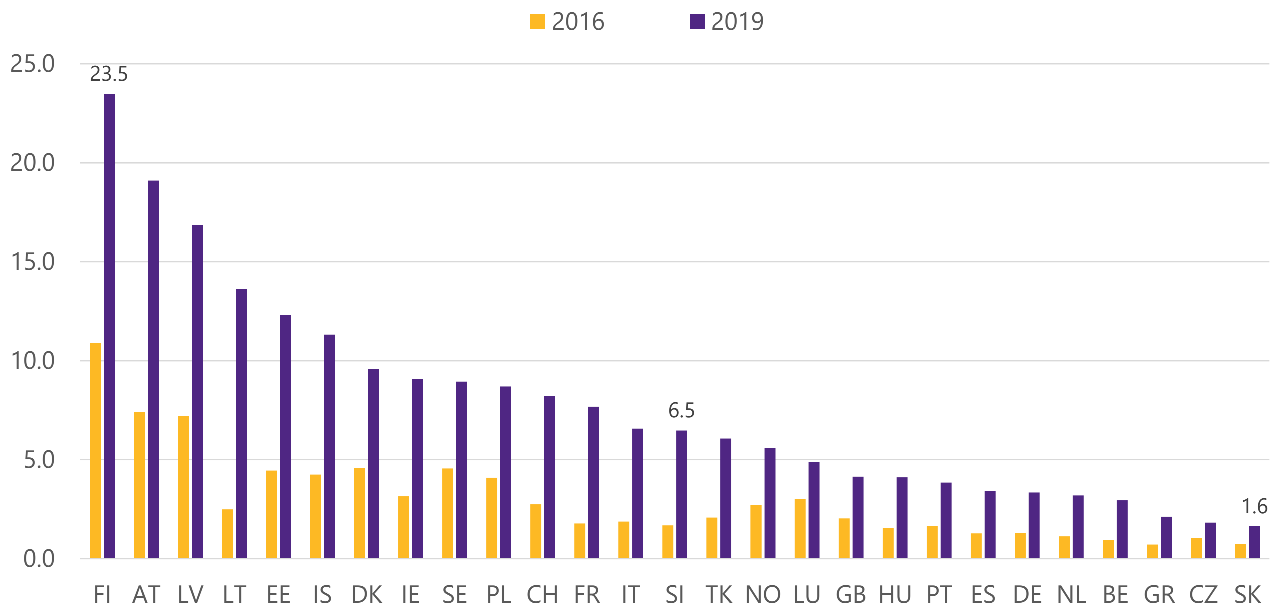
Figure 2.2: Growth in demand for Internet data[20]



The growth in mobile data demand is a global phenomenon. While there are significant variations, mobile data consumption in selected middle and high income countries in ITU Region 1 has expanded across the board between 2016 and 2019 as illustrated in Figure 2.3. As of 2019 monthly data usage per subscriber in Finland is 23.5 GB, more than 14 times than of Slovakia. The median is 6.5 GB (Slovenia).

[17] https://www.communications.gov.au/have-your-say/new-rules-new-media-landscape-modernising-television-regulation-australia
[18] https://www.coms-auth.hk/filemanager/statement/en/upload/558/600_700_mhz_statement.pdf
[19] https://www.citc.gov.sa/ar/new/publicConsultation/Documents/Spectrum%20Outlook%20for%20Commercial%20and%20Innovative%20(2021-2023).pdf
[20] Cisco (2019). Cisco Visual Networking Index: Forecast and Trends, 2017–2022.

Figure 2.3: Mobile data demand in selected Region 1 countries (GB per sub per month)[21]



This growth of traffic demand is reflected across the whole of Region 1 and is even more pronounced in developing nations. The GSMA notes:

> **"Mobile data consumption in Sub-Saharan Africa will grow more than fourfold to 2025, spurred by increased smartphone adoption and availability of affordable high-speed networks. It is expected to increase from 1.6 GB per subscriber per month in 2019 to 7.1 GB per subscriber per month in 2025 "**[22]

The increase in demand is driven by a number of factors:

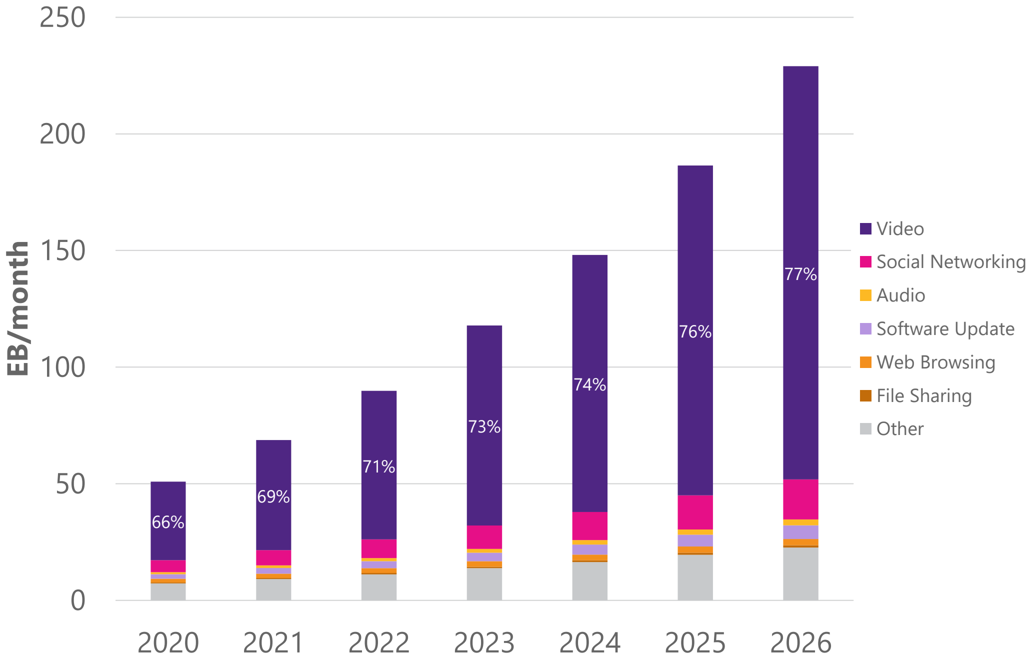
- Increasing numbers of users for many traditional services, such as email and Internet research, supported by affordable devices;
- Rapid adoption of digital services including e-commerce, financial and government services;[23,24]
- Increasing data demands for developing immersive media-rich services, such as dynamic websites and new online gaming technologies and extended reality (XR) applications;[25]
- Growing video requirements, driven by greater capabilities of new devices, improved networks, and services such as video-on-demand (VOD) and video-sharing, live streaming apps and group video calling; and

[21] OECD, Broadband Portal, http://www.oecd.org/sti/broadband/broadband-statistics/
[22] GSMAi, 2020, The Mobile Economy Sub-Saharan Africa. Available at: https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/09/GSMA_MobileEconomy2020_SSA_Eng.pdf
[23] OECD (7 October 2020). E-commerce in the times of COVID-19. Available at https://www.oecd.org/coronavirus/policy-responses/e-commerce-in-the-time-of-covid-19-3a2b78e8/
[24] World Bank (26 May 2020). Digital services help governments deliver solutions during COVID-19. Available at https://blogs.worldbank.org/governance/digital-services-help-governments-deliver-solutions-during-covid-19
[25] These cover augmented reality (AR), mixed reality (MR) and virtual reality (VR) applications across a wide range of use cases.

- New use cases, such as ultra-reliable low latency connections and massive Internet of Things (IoT) across areas such as industrial automation, advanced manufacturing, transportation and logistics, agriculture, smart metering, utility grids and environmental monitoring.

One of the main drivers of data demand is video. It is estimated that in 2020 that almost 60% of all Internet traffic was video-based.[26] On mobile networks video traffic accounts for 66 percent of all data traffic in 2020, and this is forecast to increase to 77 percent in 2026 as illustrated in Figure 2.4.[27] Online video consumption has grown rapidly in recent years – in 2020 it is estimated that viewers on average spent nearly eight hours (seven hours, 55 minutes) per week watching various types of online video content, up 85 percent from 2016 (4 hours, 17 minutes).[28] Smartphones and tablets tend to be the preferred mode of video viewing by many consumers, accounting for 60% of video views globally with the proportion in developing markets even higher.[29]

Figure 2.4: Mobile traffic by application category[30]



Another factor is the adoption of mobile devices and connected TV sets with higher resolution screens, at 4K or 8K resolution, which require exponentially larger bandwidths to deliver content. Moving from 1080p to 4K resolutions requires approximately five times the bandwidth, depending on the video codec used. Despite improvements in codec efficiency as shown in Figure 2.5, moves to higher resolutions are still requiring significantly more bandwidth than was needed in previous years. While the next generation of codecs, such as H.266 or AV1, will deliver further improvements, the bandwidth requirements of future VR applications are likely to be one or two order of magnitudes larger.[31]

[26] Sandvine (2021), Global Internet Phenomena, available at https://www.sandvine.com/phenomena
[27] Ericsson (November 2020). Ericsson Mobility Report.
[28] Limelight Networks (2020). The State of Online Video 2020. Available at https://www.limelight.com/resources/market-research/state-of-online-video-2020/
[29] Brightcove (August 2020). Q2 2020 Global Video Index. Available at https://www.brightcove.com/en/blog/top-5-media-insights-brightcoves-q2-global-video-index/
[30] Ericsson (November 2020). Ericsson Mobility Report.
[31] Mangiante, S et al. (2017). VR is on the Edge: how to deliver 360° videos in mobile networks. Available at https://dl.acm.org/doi/pdf/10.1145/3097895.3097901

Figure 2.5: Bandwidths required for video streaming[32]

Resolution	Required Bandwidth (H.264)	Required Bandwidth (H.265)
720p	3Mbps	1.5Mbps
1080p	6Mbps	3Mbps
3840×2160 (UHD)	25Mbps	12Mbps
4096×2160 (4K)	32Mbps	15Mbps

The Covid-19 pandemic has accelerated the use of the internet for day-to-day economic and social activities, such as work, school and entertainment, and for essential needs, such as shopping, banking, financial and public services. Many of these step changes in behaviour are likely to persist after the pandemic has subsided. One of these is the mass adoption of video-conferencing and online collaboration tools, such as Microsoft Teams, Zoom, FaceTime and WhatsApp, for both work and personal communications. The use of these services are likely to increase remote working and reduce the future need for long-haul business travel. The pandemic has also emphasised the divide between rural and urban communities, leaving deep rural areas into almost isolation and thus creating a bigger gap in society.

The main bottleneck for internet connectivity is generally the access network, whether over a wireless link or a physical fixed line, and associated backhaul. The dependence on wireless connections is particularly important in deep rural areas where access by fibre networks is not economically viable. The potentially permanent shift towards remote living and working will also affect the nature of network requirements due to rising uplink bandwidth demand for video calls.[33]

Finally, while some industrial applications, such as smart monitoring, telemetry, sensors and utility meters, may require lower bandwidths, the reliability of connections used for low-latency messaging or marketplaces is a crucial input to their work. The importance of these connections is difficult to show on aggregated metrics, but should not be underestimated.

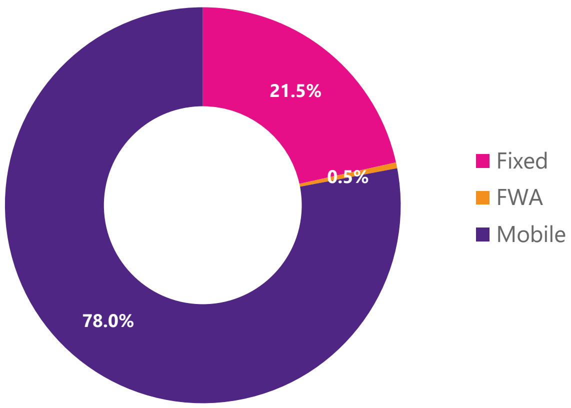
2.2.1 Mobile connections are increasingly important

The previous section has identified the increasing importance of high-bandwidth and low-latency Internet connectivity for productivity, social welfare, and wellbeing. Alongside the growth in dependence on such connections, many countries are seeing a greater reliance on wireless technology – both mobile and fixed wireless – to meet growing demand for affordable and expandable connectivity. Figure 2.6 below shows the percentage of mobile and fixed broadband subscriptions in OECD countries.

[32] Khaled (2019): "Bandwidth Required For HD FHD 4K Video Streaming", available at https://www.synopi.com/bandwidth-required-for-hd-fhd-4k-video/

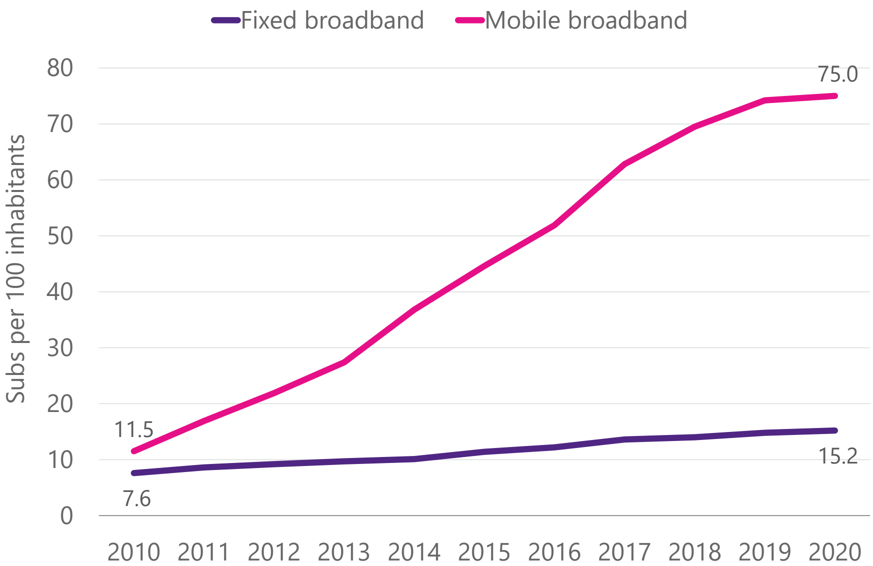
[33] Unlike typical video applications which are predominantly downlink, the bandwidth requirements video-conferencing applications are typically symmetric in uplink and downlink. For example, see system requirements for Zoom https://support.zoom.us/hc/en-us/articles/201362023-System-requirements-for-Windows-macOS-and-Linux

Figure 2.6: Broadband subscriptions by technology in OECD countries, June 2020[34]



On the whole, adoption of mobile broadband has grown much more rapidly than fixed broadband as shown in Figure 2.7 – in the last 10 years the mobile broadband adoption has increased 6.5-fold compared to a 2-fold increase for fixed broadband.

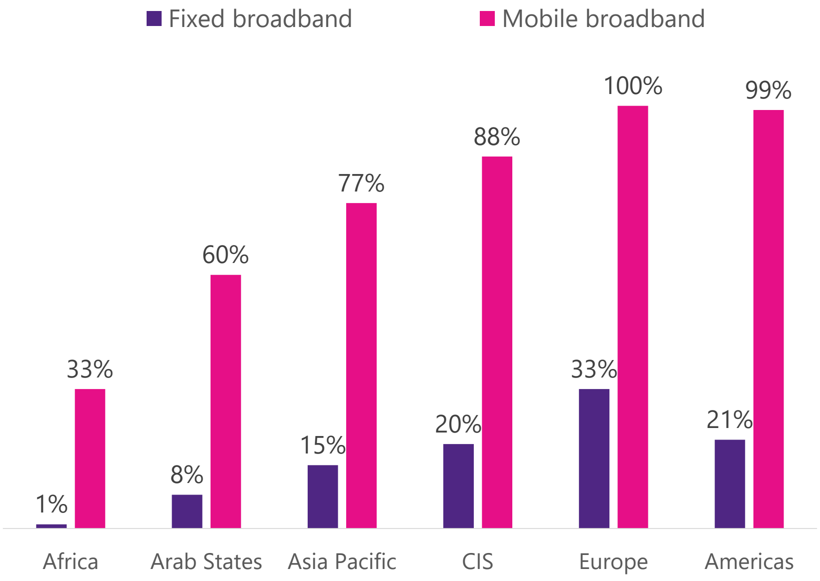
Figure 2.7: Global broadband adoption trends[35]



The mix between fixed and mobile connections varies by region as shown in Figure 2.8 In Europe and the Americas, mobile broadband penetration is close to 100% while fixed broadband adoption is relatively widespread compared to the rest of the world. In developing regions, particularly in Africa, the vast majority of connections are mobile due to less extensive fixed broadband infrastructure and greater affordability of mobile devices and services.

[34] OECD. Broadband Portal.
[35] ITU (2020). Measuring digital development: Facts and figures. Available at https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx

Figure 2.8: Type of broadband subscriptions per 100 inhabitants by region, 2020[36]



Mobile connections are increasingly becoming the most prevalent way of connecting to the Internet. The growing adoption of smartphones, along with the proliferation of mobile apps, is driving innovation across industry sectors and enabled a wide range of economic and social benefits.[37] Some of the previous barriers to this growth of mobile as the primary connection – of high data costs, metered connections, and low speeds – are becoming less prevalent over time.

The advancement of mobile technology, particularly with 5G, means the gaps in capability and performance between fixed fibre and mobile connectivity services are being narrowed. The applications and services used on mobile connections are similar to those carried over fixed-line links. While it is expected that file sharing will be less prevalent on mobile devices, and social networking more common, the biggest application in terms of data usage and bandwidth requirement remains video. Mobile technology to bring people "online" is particularly important in deep rural areas, where fixed-line connections are unavailable or of poor quality.

Video consumption on mobile networks these days is mainly comprised of video-on-demand (VOD) and video-sharing services which have been gaining popularity in recent years (see Section 3.4 below). These over-the-top (OTT) services are typically delivered via the public Internet in unicast (one-to-one) mode.[38] Alternate modes of video delivery, namely broadcasting (one-to-all) and multicast (one-to-many) are less suitable for mobile reception. Multicast streaming is mainly used for IPTV service delivery via set-top boxes and TV broadcasting has traditionally been for fixed reception to TV sets.[39]

This huge growth in video services is a significant factor impacting on the design and requirements of mobile networks. While in the past it was reasonable to cover less populated areas with a basic mobile network connection, the requirements of consumers and businesses is changing so that all connections must be capable of high-quality video streaming.

[36] ITU (2020). Measuring digital development: Facts and figures.

[37] For example, see Deloitte (2020). The App Economy in the European Union: a review of the mobile app market and its contribution to the European Economy. Available at https://actonline.org/wp-content/uploads/Deloitte-The-App-Economy-in-the-EU-2020.pdf

[38] For a given audience size, unicast streaming is more bandwidth intensive than multicast or broadcast delivery. Thus, major OTT video services, such as Netflix and Amazon Prime Video, rely on content distribution networks (CDNs) to manage unique unicast streams across the Internet and share the traffic load.

[39] While broadcast mobile TV in the form of DVB-H was introduced in a number of markets globally in the mid-2000s, it failed to gain wide adoption and most services were discontinued by the early 2010s.

2.2.2 Fixed wireless access is an important part of the mobile ecosystem

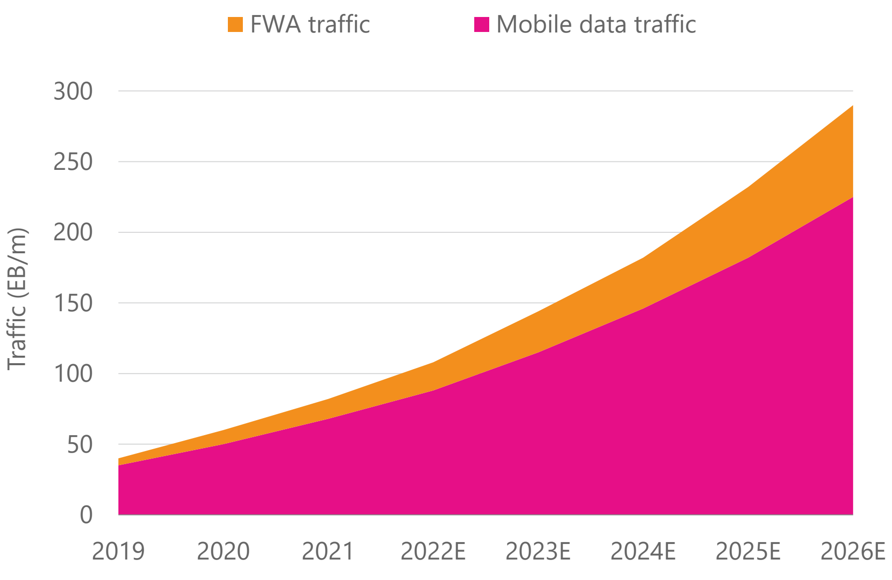
As well as pure mobile connections, an increasing proportion of fixed lines are now provided using fixed wireless access (FWA) solutions within the mobile service. In more sparsely populated regions where the costs of deploying high-speed broadband via fixed-line infrastructure is not economically feasible, the significantly lower capital expenditure of FWA provides a viable way of reaching many households. Rather than installing fibre throughout a town, a single base station can deliver high speed connections to several hundred premises, and this requires with some relatively inexpensive equipment at the consumer premises.

Previously, many FWA networks relied on proprietary technology to deliver services, including WiMAX or even dedicated fixed links. However, these tended to require significant expenditure in dedicated networks, and suffered from latency issues or offered variable speeds. A number of service providers offered FWA using LTE TDD technology during the 2010s, which could provide a greater speed than some of the older WiMAX networks, but, crucially, could be run alongside mobile LTE networks to minimise costs. LTE was also used in hybrid models in rural areas where long copper lines limit DSL performance.

With 5G NR technologies, the same networks can be used for mobile and FWA services, again reducing costs and increasing capabilities – including, importantly, a significantly reduced latency. This will make FWA increasingly attractive for rolling out high speed connections to the most remote locations. Ericsson estimates[40] that by 2026 there will be 180 million FWA connections globally, which would represent just under 20% of all fixed connections[41].

With the move to 5G networks capable of serving both mobile and FWA customers – potentially using a combination of low (sub-1 GHz), mid (1-7 GHz), and high-band (above 7 GHz) spectrum to give a good coverage and capacity portfolio – it is important that this sector is not ignored when considering spectrum demands for 5G.

Figure 2.9: Data traffic over 5G spectrum[42]



FWA services will rely on mmWave spectrum in dense localised areas, and on mid-band spectrum in town centres and small villages to deliver fibre-like high-capacity connectivity. UHF spectrum will continue to have an

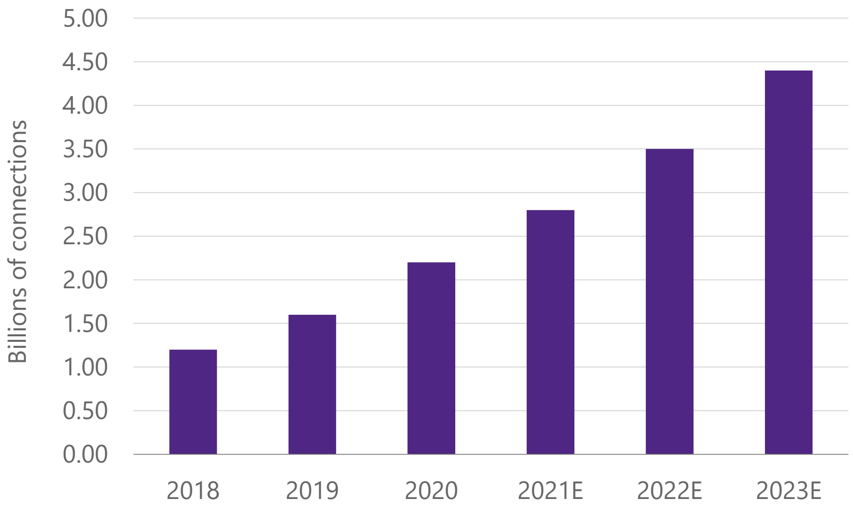
[40] See https://www.ericsson.com/en/mobility-report/dataforecasts/fwa-outlook
[41] Statista (at https://www.statista.com/statistics/273014/number-of-fixed-telephone-lines-worldwide-since-2000/) estimates there were 915 million fixed lines worldwide in 2019.
[42] Source: https://www.ericsson.com/en/mobility-report/dataforecasts/fwa-outlook

important role for FWA, particularly in developing markets, and in the most remote locations, households may be able to receive a 5G FWA solution using UHF where previously they had no option for broadband at all.

2.2.3 There is significant growth in the Internet of Things

The mobile ecosystem is not just restricted to consumer phones, but has grown to include a large number of machine to machine (M2M) or Internet of Things (IoT) devices. Indeed, the number of these devices is growing at such a rate that by 2024 they are predicted to outnumber consumer mobile handsets.

Figure 2.10: Growth in M2M devices[43]



The network requirements of IoT and M2M devices varies considerably. Some devices, which are connected only to report back an occasional value such as an hourly temperature or stock level alerts, require very low bandwidth. Some, such as those analysing high definition videos for facial recognition purposes, would require a high speed capability. Others, such as those controlling vehicle movements, would require both a relatively high bandwidth and also a low latency.

It is fair to say that there will only be a subset of IoT connections requiring small bandwidth that are currently suitable over UHF spectrum, given the lower bandwidths available. However, for those being used in rural areas the high number of connections which can be supported from a single base station will make a 5G-based network economically viable. Further, if more UHF spectrum is made available to networks, the capabilities of these rural networks for IoT devices will increase, allowing newer technology to be used to increase productivity while keeping the cost per transmitted bit low. At the same time, UHF spectrum can also help to support some IoT applications in deep indoor or underground areas where it may be difficult or costly to deploy bespoke infrastructure. [44]

For example, John Deere, a large provider of agricultural equipment, has been rolling out smart sensor technology on tractors for the past two years[45]. Currently these are restricted to identifying the volume and spacing of seeds, but there could be a large number of other sensors to help farmers make their planting and

[43] Source: Cisco Annual Internet Report, 2018-2023
[44] These might be in urban or rural locations though it is likely that alternative means of provision using licensed or unlicensed spectrum are more readily available in urban locations.
[45] See https://Internetofbusiness.com/john-deere-turns-iot-smart-farming/

harvesting more efficient. Reducing the cost of this equipment will have a significant impact on rural and developing areas.

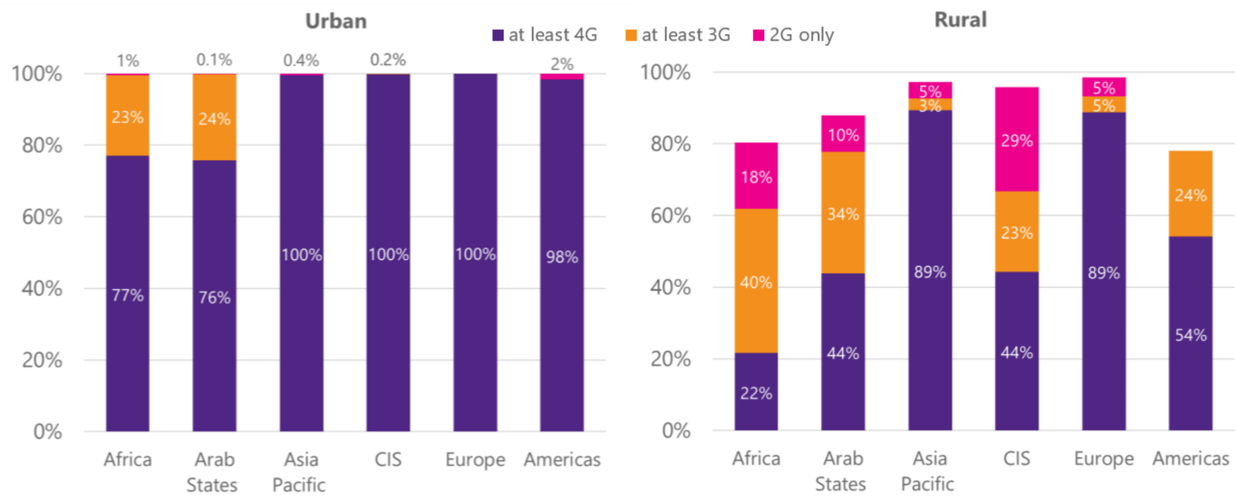
2.3 Mobile coverage varies significantly between urban and rural areas

As of the end of 2019, 600 million people were still living outside of areas covered by mobile broadband networks – this amounts to 7% of the world's total population.[46] Most of this population is from rural areas – both in developed and developing countries, but more so in the latter. As well as this population who are entirely uncovered, millions more live in regions with poor signal quality, instable and irregular connectivity, and often covered only by older technologies.

Figure 2.11 below shows the mobile coverage by population in rural and urban areas of different parts of the world, split by technology as of 2020 (excluding 5G).[47] In urban areas, the overall mobile coverage is significantly higher than rural areas, with almost 100% of urban population having access to at least some form of mobile broadband network (3G or 4G). While there is a clear difference between urban and rural broadband coverage across all regions, the gap is more pronounced among countries in Africa, Middle East, Central Asia and the Americas.

The differences in the availability of mobile technologies between urban and rural areas also reflect a significant urban-rural gap in terms of mobile service performance. For instance, even in Germany where mobile infrastructure is highly advanced, there are considerable differences in availability and download speed experience across urban and rural areas.[48] Thus, not only is there a need to extend rural coverage, it is also important to ensure improved network performance by deploying more advanced technologies with UHF spectrum to close this gap and narrow the digital divide. Without this investment, it is possible that rural users will be unable to access more advanced services.

Figure 2.11: Mobile broadband coverage by population (urban vs rural), 2020[49]



[46] GSMAi (2020). The State of Mobile Internet Connectivity. Available at https://www.gsma.com/r/wp-content/uploads/2020/09/GSMA-State-of-Mobile-Internet-Connectivity-Report-2020.pdf

[47] While 5G is not included in this analysis, 5G deployment has started in many advanced markets globally over the last two years, although 5G rollout and coverage is so far mainly concentrated in urban areas, with relatively little penetration into rural areas.

[48] Opensignal (2020). German rural 4G users see big differences in 4G Availability and download speeds between operators, 12 March 2020. Available at https://www.opensignal.com/2020/03/12/german-rural-4g-users-see-big-differences-in-4g-availability-and-download-speeds-between-operators

[49] ITU (2020). Measuring digital development: Facts and figures 2020. Available at https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx

While mobile broadband coverage is lower in rural areas compared to urban, it is a crucial method of expanding the reach of telecommunications networks. Fixed networks are prohibitively expensive in deep rural areas, since the cost of rollout is impacted directly by the distance between subscribers. This is true in both developed and developing countries.

In Ireland, eir (the incumbent fixed line provider) has a universal service obligation whereby it must provide a fixed line to any premises that requires one. However, there is a cost threshold included in the legislation: if it would cost over €7,000 to provide the line, eir may charge any additional cost to the customer. This has led to over 500,000 people not having access to a reasonable cost fixed line broadband service.

In South Africa, there are many areas of the country which are a significant distance from the fibre backbone network, particularly in the North and North-West of the country, as can be seen in Figure 2.12. Towns which are a long distance from these backbone networks will require expensive long-distance fibre links or a number of microwave connections for connection, increasing the cost of the network and potentially reducing reliability.

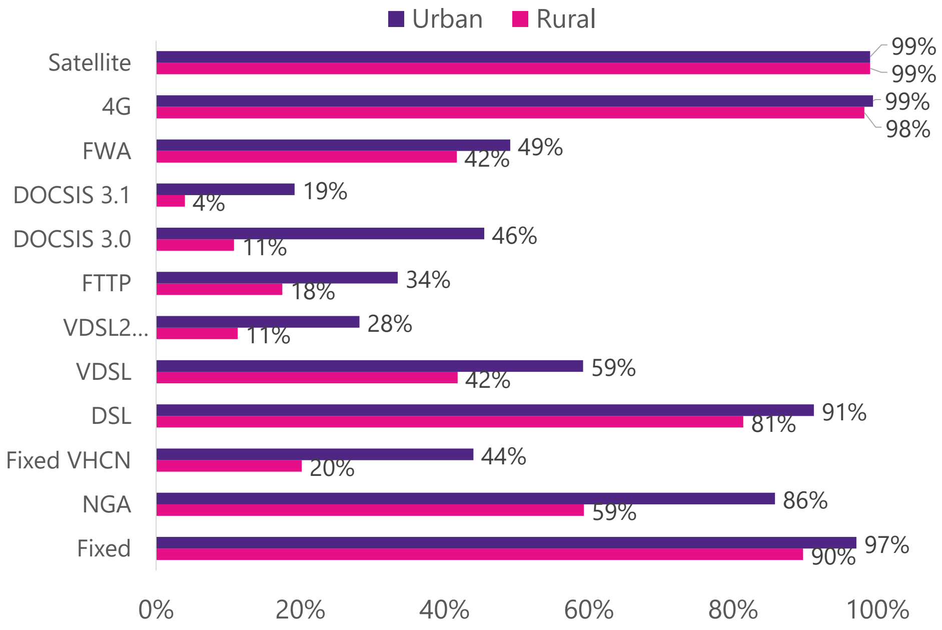
Figure 2.12: South African backbone fibre networks[50]

In many developed countries there is a Universal Service Obligation on fixed operators (to provide all consumers with an adequate level of broadband service[51]) due to the historical importance of fixed networks. However, this type of requirement is unrealistic in many developing countries due to a lack of historic investment. Without the use of mobile technologies, there would be a vast population in deep rural areas with no telecommunications at all, let alone mobile broadband.

The difference in fixed line connection quality and availability can be clearly seen across Europe by looking at the overall coverage of different technologies, shown in Figure 2.13. While the EU is relatively developed by global standards, there remain some significant areas where connectivity is unavailable, particularly in rural areas. While overall coverage is high (at 90% of rural areas), the proportion of these which are receiving a 'next generation' services (of FTTH or better) is significantly worse in rural areas (59%) than urban areas (86%).

[50] Source: ICASA
[51] For example, in the UK, BT is obliged to provide any address that requests it a broadband connection of at least 10 Mbps downlink and 1 Mbps uplink. However, there are limits on the cost which BT is obliged to provide. For more information see https://www.bt.com/broadband/USO

Figure 2.13: EU broadband coverage by technology (2019)[52,53]



In Figure 2.13 above we can see that LTE (4G) coverage is almost ubiquitous, and allowing 5G to use UHF spectrum in sufficient bandwidths can bring coverage of that technology to a similar level as 4G. The benefits particularly in rural areas where alternative modes of very high-capacity broadband connectivity (VHCN) infrastructure are less available are expected to be significant. For example, this would contribute to the development of smart rural use cases, such as agriculture applications and 5G FWA, which can deliver substantial socio-economic and environmental benefits.

The availability of fixed line networks is even lower in in Africa, the Middle East and CIS and thus it is crucial that wireless technologies can be used to fill this gap.

2.3.1 Coverage on transport routes

While regulators tend to consider coverage in terms of urban and rural areas, an increasingly important part of mobile coverage is along transport routes. The European Commission's 5G Action Plan includes the target for all Member States to ensure uninterrupted 5G coverage in urban areas and along main transport paths by 2025.[54] As part of the Strategic Deployment Agenda for Connected and Automated Mobility, these "5G corridors" are expected to be a key enabler for connected and automated mobility and for the development of innovative ecosystems around cars and other means of transport.[55]

Although these routes often travel through rural areas, the population density on average of these routes (both road and rail) is much higher. This makes it significantly more profitable to roll out mobile networks along these routes. In addition, the nature of consumers on these routes makes the alternative of a fixed connection impossible.

[52] European Commission (2020). Digital Economy and Society Index Report 2020 – Connectivity. Available at https://ec.europa.eu/digital-single-market/en/broadband-connectivity#:~:text=Across%20Europe%2078%25%20of%20households,higher%20than%20five%20years%20ago

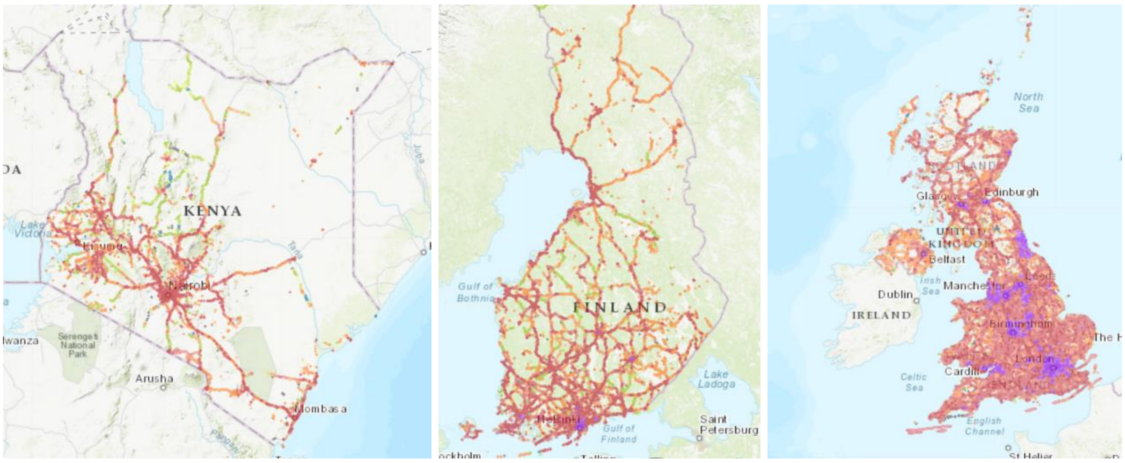
[53] Fixed broadband coverage includes DSL, VDSL, VDSL2 Vectoring, FTTP, DOCSIS 3.0, DOCSIS 3.1, FWA; NGA coverage includes VDSL, VDSL2 Vectoring, FTTP, DOCSIS 3.0, DOCSIS 3.1; Fixed Very High Capacity Network (VHCN) coverage includes FTTP and DOCSIS 3.1 coverage; DSL figures include VDSL and VDSL2 Vectoring coverage; Cable DOCSIS 3.0 figures include DOCSIS 3.1 coverage.

[54] European Commission. Europe's 5G Action Plan. Available at https://digital-strategy.ec.europa.eu/en/library/europes-5g-action-plan

[55] European Commission (8 March 2021). Europe sets 5G investment agenda for Connected and Automated Mobility. Available at https://digital-strategy.ec.europa.eu/en/news/europe-sets-5g-investment-agenda-connected-and-automated-mobility

It is clear to see from existing measured coverage maps how mobile networks have evolved along transport routes. Even in more developed nations, rural areas (such as the North of Scotland or Oulu in Finland) are sparsely covered, other than along major road and rail routes.

Figure 2.14: Measured mobile coverage by LTE (orange), LTE-A (red), and 5G (purple)[56]



The importance of high quality connections on transport networks is well known to regulators, as well.

- In Germany, a coverage obligation was included in the 5G spectrum award process, requiring that (by the end of 2022) all motorways must be covered with a minimum speed of 100 Mpbs (with maximum 10ms latency), as well as most federal roads and railways; by the end of 2024 this would be extended to all other federal highways, and all other roads, waterways and railways would have a 50 Mbps obligation.

- In Saudi Arabia, 5G licences required that by 2022, the average experienced download speed across all highways must exceed 10 Mbps, rising to 50 Mbps by 2025.

In both these cases, although the obligations were placed on certain 5G spectrum awards, there was no requirement for this spectrum to be used to provide the service. It was understood that in more remote areas, low-frequency spectrum would be required for an economic network.

Although the business decision on how to roll out coverage to transport routes is similar to that made over coverage in all rural areas, there are some unique characteristics which operators must take into account.

- First, the consumers on these routes are not at their home or work, or other fixed location – it is not possible to determine a consistent usage pattern. This means that consumers will value coverage of transport routes in a different way to coverage in their typical locations.

- The type of usage along these routes will differ, as well as the value of the services provided. Basic coverage, to enable rescue or emergency cover, will be very highly valued, but there will be little value of protocols enabling file sharing.

- Increasingly, however, consumers – passengers on trains or in cars – will demand access to streaming video and lower latency connections for video calls or online gaming.

- Transport links are typically relatively straight lines over long distances. This means it is efficient to cover these with spectrum with a long cell radius. Transport links that are not extremely busy are best served

[56] Source: https://www.nperf.com/

by using lower frequency spectrum, requiring not only are fewer base stations but also there will be less handover between sites, again improving service quality.

The benefits of an expanded bandwidth of UHF spectrum here are clear. Operators will not find it economically feasible to roll out a dense straight-line C-band network for 5G coverage over all transport paths, but directional UHF antennae on fewer base stations will provide a much higher quality and reliable service. On more dense roads, this should be supplemented with mid-band frequencies, but the UHF coverage layer will remain vital.

Furthermore, coverage of transport routes is not needed only for mobile broadband. In the 5GAA Working Group report on spectrum needs for safety-related intelligent transportation systems[57], the study noted both the need for UHF and mid-band spectrum. In addition at least 500 MHz in the 1-7 GHz range for city-wide vehicle-to-network (V2N) communications, the UHF spectrum requirement includes:

> **“At least 50 MHz of additional service-agnostic low-band (< 1 GHz) spectrum would be required for mobile operators to provide advanced automotive V2N services in rural environments with affordable deployment costs.”**

Such an allocation of UHF spectrum would not be possible on current band plans when division between mobile operators is taken into account.

2.4 Rural coverage will bring significant benefits

Inhabitants of rural areas, who have long depended on telephones for social contact, are now reliant on mobile connections to take part in social and economic activity – this has been heightened by the social lockdowns and restrictions caused by the Covid-19 pandemic in recent months. Expanding coverage of high-quality broadband in deep rural areas can improve the economic wellbeing of people, improve their lives through access to health facilities, education and other essential services.[58] A recent report examining mobile networks in Switzerland found that rural areas were driving data traffic growth and that network upgrades to increase capacity is urgently needed to meet increasing demand.[59] The ability to deliver consistent, high-quality broadband in deep rural areas is thus crucial to bridging the digital divide, reducing rural-urban inequality and enhancing social and economic resilience.

It is important to note that this potential digital divide not only concerns the ability to get a connection, but is also about the quality of that connection. Governments and regulators have worked alongside network operators to expand the coverage of mobile telecommunications, and as shown above the majority of the world can receive some service. However, consumers in rural and deep rural areas often experience lower speeds and less reliable connections, largely driven by the higher costs associated with rolling out networks in less dense areas.

This section discusses various case studies from rural areas in both developing and developed countries on how access to high quality mobile broadband benefits society.

[57] See https://5gaa.org/news/study-of-spectrum-needs-for-safety-related-intelligent-transportation-systems-day-1-and-advanced-use-cases/

[58] For example, a report by UNICEF and ITU estimated around three-quarters of school-age (3-17 years old) children in rural households do not have internet access at home, compared to around 60 per cent in urban households. See UNICEF-ITU (2020). How many children and young people have internet access at home? Available at https://www.unicef.org/press-releases/two-thirds-worlds-school-age-children-have-no-internet-access-home-new-unicef-itu

[59] Sotomo (May 2021). Using Mobile Data in Switzerland. Available in German at https://sotomo.ch/site/wp-content/uploads/2021/05/Mobile-Datennutzung-Schweiz.pdf

2.4.1 Impact on economic wellbeing

A December 2020 study by the World Bank and GSMAi studied the impact of mobile broadband on welfare and poverty reduction in Nigeria – one of the most significant mobile markets and economies in Africa. This study found that one year of mobile broadband coverage increased total consumption in the economy by about 6%. This estimate reaches 8% after two years of coverage. Further, the proportion of households below the extreme poverty line ($1.90 per day) would drop by about 4 percentage points after one year of gaining mobile broadband coverage and by about 7 percentage points after two or more years of coverage. The key mechanisms identified for these results are increased labour force participation and employment, particularly in women. [60]

A number of studies prior to this have also found a positive impact of broadband coverage in enhancing the economic well-being of people through various mechanisms. These include:

- **Increased access to inputs**: allowing people to access inputs to improve their businesses or agricultural production. For example, broadband connections can provide constant access to latest research and knowledge along with an opportunity to reach out to experts to improve business. Aker (2011) outlines potential mechanisms like broadband, voice, text, and mobile money transfers through which ICT could facilitate agricultural adoption and the provision of extension services in developing countries.[61]

- **Access to capital markets**: broadband connections allow people to use mobile money which helps them to make payments or transfers using a mobile phone without a cheque or cash. In developing countries where the banking infrastructure is not well developed, mobile money allows people to make bank transfers smoothly and works as a useful alternative. Hasbi and Dubus (2019) use micro-level data coming from household surveys over 5 years, from 2013 to 2017 in four Sub-Saharan African countries namely Nigeria, Kenya, Tanzania and Uganda. They found a positive correlation between digital inclusion and financial inclusion as mobile money users and bank account users are found to be more inclined to use mobile broadband. [62]

- **Improvement in labour market outcome**: access to Internet makes it easy for people to look out for a greater number of job opportunities which is not possible by looking out for roles in print media (newspapers and magazines) or through contacts or references. This potentially allows more people to seek jobs, increasing the labour market participation. Viollaz and Winkler (2020) found that Internet adoption increased the female labour force participation in Jordan between 2010 and 2016, though it had no effect on male labour force participation.[63] Hasbi and Dubus 2019 also found that mobile broadband is used to look for jobs by the unemployed. [64]

  Further, access to broadband can also improve the productivity of firms at different development stages. Paunov and Rollo (2014) found this relationship, based on 49,610 firm observations across 117 developing and emerging countries for 2006–2011.[65]

[60] GSMAi and World Bank, Dec 2020, The poverty reduction effects of mobile broadband in Africa: Evidence from Nigeria. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/12/The-Poverty-Reduction-Effects-of-Mobile-Broadband-in-Africa-Evidence-from-Nigeria.pdf

[61] Aker, 2011, Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries, Wiley Online Library. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1574-0862.2011.00545.x

[62] Hasbi and Dubus 2019, Determinants of Mobile Broadband Use in Developing Economies: Evidence from Sub-Saharan Africa. EconPapers. Available at: https://hal.archives-ouvertes.fr/hal-02264651/document

[63] SSRN, March 2020, Does the Internet Reduce Gender Gaps?: The Case of Jordan. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3554092

[64] Hasbi and Dubus 2019, Determinants of Mobile Broadband Use in Developing Economies: Evidence from Sub-Saharan Africa. EconPapers. Available at: https://hal.archives-ouvertes.fr/hal-02264651/document

[65] Paunov and Rollo, April 2015, Overcoming Obstacles: The Internet's Contribution to Firm Development, Oxford Acdemic. Available at: https://academic.oup.com/wber/article/29/suppl_1/S192/1686970?login=true

- **Positive wage effects**: people's wages can improve because of access to more job opportunities via broadband. Those that did not have a job before could now find one, and at the same time, people can also find better paying roles and improve their existing incomes. Klonner and Nollen (2010) find that rural employment increased by 15 percentage points in South Africa after the roll-out of mobile network in the region. Most of this effect was due to increased employment by women, in particular those who are not burdened with large childcare responsibilities at their homes.[66]

2.4.2 Impact on improving lives and equality

Improving mobile broadband coverage in rural areas has a positive impact on reducing the mobile broadband usage gap[67] between rural and urban areas (rural-urban gap) and between men and women (gender gap). The rural-urban gap has narrowed from 46 percent in 2017 to 37 percent in 2019, while the gender gap has reduced from 27 percent in 2017 to 20 percent in 2019. These trends have been majorly driven by improving mobile broadband coverage in developing countries along with improved awareness about mobile broadband and affordability.

A study was conducted by the GSMAi in various developing countries including Nigeria on studying the welfare effects of mobile broadband connectivity on the lives of the women, particularly in rural areas. It found that improved broadband connectivity positively impacted the women of different age groups. The welfare effects included better access to education, employment content and social networks, staying connected with friends and family and access to better business tools and marketing information. [68]

The study found that using mobile broadband connections, Nigerian women aspire to find consistent work and increase their earnings. They value mobile broadband for various work-related applications. The study finds that 52 percent of the women who were surveyed in Nigeria and who own smartphones use to it find new customers and suppliers, 52 percent use it to browse the Internet, 65 percent access educational content and 51 percent find new job opportunities. It is also found that in Nigeria, the women who have smartphones use email applications and social media more frequently on their mobile phones than on computers or laptops[69]. Hasbi and Dubus (2019) found that students in countries like Kenya, Tanzania and Uganda used mobile broadband for information gathering.[70]

There are numerous examples of how broadband connectivity has improved the lives of the people in Sub-Saharan Africa[71]. Some of these are discussed below.

- In July 2020, Safaricom partnered with Google to launch the Lipa Mdogo payment plan in Kenya, allowing customers with 2G and a daily wage to purchase a 4G smartphone for a deposit of KES1,000 ($10) and daily instalments of KES20 using M-Pesa within 9 months. The daily payment reflects the financial culture of low-income users – who earn a daily wage and prefer smaller regular payments.

[66] Klonner and Nollen, 2010, Cell Phones and Rural Labor Markets: Evidence from South Africa. Available at: https://ideas.repec.org/p/zbw/gdec10/56.html
[67] This is defined as the difference in usage of mobile broadband between rural and urban areas or between men and women.
[68] GSMAi, Transforming Women's livelihoods through Mobile Broadband. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/02/transforming-women-s-livelihoods-through-mobile-broadband.pdf
[69] GSMAi, Transforming Women's livelihoods through Mobile Broadband. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/02/transforming-women-s-livelihoods-through-mobile-broadband.pdf
[70] Hasbi and Dubus (2019): Determinants of Mobile Broadband Use in Developing Economies: Evidence from Sub-Saharan Africa. EconPapers. Available at: https://hal.archives-ouvertes.fr/hal-02264651/document
[71] GSMAi (2020): The Mobile Economy Sub-Saharan Africa. Available at: https://www.gsma.com/mobileeconomy/sub-saharan-africa/#:~:text=The%20mobile%20industry%20in%20Sub,changes%20in%20data%20consumption%20patterns.&text=The%202020s%20will%20see%20strong,Africans%20connected%20to%20mobile%20broadband.

- In 2019, smartphone start-up Mara Phones partnered with several banks, including the Nedbank in South Africa and Bank of Kigali in Rwanda, to pre-finance devices for consumers, who can pay for their devices in monthly instalments of $4–6 over two to three years.

- MNOs are expected to play a key role in enabling digital payments to replace cash transactions in Sub-Saharan Africa, as online shopping becomes popular. A survey from Visa found that 71% of respondents in Nigeria and 64% in South Africa bought groceries online for the first time because of the pandemic. During the first half of 2020, pan-African online retailer Jumia also reported increased demand from sellers across the region to expand their business on its platform.

While these benefits apply across both urban and rural areas, as previously discussed there is often an option in urban areas to have connectivity provided by alternative networks. The only way to achieve connectivity in deep rural areas is by mobile, and this will require a commercially viable network with adequate UHF spectrum. As will be discussed later, current UHF holdings for mobile operators are not sufficient to provide a comparably high-quality network.

2.4.3 Improving lives through the use of IoT in rural areas

In addition to individual-level welfare effects accrued as a result of improved broadband connectivity in the rural areas, there are also industry-level benefits to be accrued through IoT and M2M growth. Cellular M2M connections are expected to grow from 256 million at the end of 2014 to 2.2 billion by 2024[72]. Harmonised mobile spectrum is needed to support all wide area IoT use cases including coverage bands (sub-1 GHz spectrum) for Low Power Wide Area (LPWA) use cases.[73] The advantage of using sub-1 GHz spectrum for these IoT use cases is the longer range combined with the need for low power consumption; as previously discussed higher frequencies are more susceptible to interference and provide less range and coverage.[74]

Safaricom in Kenya has established a number of IoT networks, demonstrating the benefits that can be realised:

- It announced plans for an NB-IoT network in 2017 and is recently using the technology to serve enterprises in various sectors. These include the implementation of a remote monitoring solution for Kenyan water utility Embu water & sanitation company (EWASCO). Using this solution, the company is able to identify optimal water flow by matching supply with the demand. Further, it has made possible to track real-time consumption of water to ensure adequate supply during a critical period like the ongoing COVID-19 pandemic.

- It launched a prepaid gas service along with M-Gas and M-Pesa using its own NB-IoT network. The solution improves the affordability for users while also giving them more control over usage and replenishment of cylinders.

- It partnered with Kenya Breweries Limited (KBL) to connect and enhance its coolers using the IoT technology. Sensors that are connected to the coolers monitor different factors like – temperature, how often the fridge door is opened and so on, and the real time data is provided to KBL.

For Europe, a study by Analysys Mason[75] on the 5G Action Plan concluded that the largest economic benefit in terms of GDP contribution would be from smart factories, smart agriculture and 5G FWA in sub-urban and rural

[72] LPRS, Sub-1GHz Radio: Best Solution for the IoT? Available at: https://lprs.co.uk/about-us/news-and-events/rf-articles/sub1ghz-radio-solution-for-iot.html

[73] GSMAi, 3GPP Low Power Wide Area Technologies. Available at: https://www.gsma.com/iot/wp-content/uploads/2016/10/3GPP-Low-Power-Wide-Area-Technologies-GSMA-White-Paper.pdf

[74] LPRS, Sub-1GHz Radio: Best Solution for the IoT? Available at https://lprs.co.uk/about-us/news-and-events/rf-articles/sub1ghz-radio-solution-for-iot.html

[75] Analysys Mason, September 2020, 5G action plan review for Europe: final report.

areas, building on existing eMBB infrastructure in low, mid and high bands.[76] Low bands are especially critical for rural use cases.

Another case study was undertaken by Nokia[77] looking at the example of BMW Remote Services in the urban underground parking structures in Aalborg, Denmark, and open rural areas with poor LTE coverage in South Germany. This study assessed the functioning of the remote services like locking and unlocking the doors, sounding the horn, climate control, activating the headlights or sending navigation destinations in advance and passenger entertainment applications like music streaming, using LTE eMTC and NB-IoT technologies on the 800 MHz band. The results revealed that a minimum of 60 – 70 percent of the total indoor underground parking locations can be served from an outdoor macro LTE 800MHz cell while full eMTC or NB-IoT radio coverage can be provided in rural areas. Given the locations studied, higher frequency spectrum was significantly less useful.

2.5 UHF is the only realistic way to achieve deep rural connectivity

The analysis above has demonstrated the need for high-bandwidth, high-quality (mobile) broadband networks in sparsely populated, deep rural areas. In the case of transport networks, the need for the connection to be mobile is driven by the (changing) location of the user; in the case of general deep rural coverage the need for mobile broadband is driven by economics.

It is worth noting that the emergence of Low-Earth Orbit (LEO) satellite broadband services will help address the lack of fixed broadband infrastructure in rural areas. However, despite improvements in satellite connectivity, there are certain characteristics of satellite which means it is likely to be complementary to, rather than a substitute for, mobile broadband. Compared to mobile broadband, a satellite broadband service is limited in mobility, has a relatively higher latency, and may have significantly lower capacity. In addition, the equipment required is significantly more complex.

There remain significant areas of many countries – both developed and developing – where there is inadequate mobile coverage. This is caused by two factors:

- Low levels of demand, or a low willingness or ability to pay, meaning that operators would see little benefit from expanding coverage to these areas; and
- Higher costs of network deployment[78], since both capital costs and operating costs for deep rural base stations are significantly higher than those for urban base stations.

Investment in these uncovered areas is therefore unprofitable. In order to encourage operators to increase the coverage of networks, and to roll out the benefits of connectivity to as many people as possible, the cost of deployment must be reduced. This can be achieved by using lower band spectrum, lengthening the distance between base stations (since additional base stations will not need to be commissioned to add the capacity needed for high performance) and reducing the amount of equipment needed.

This is particularly the case where there is some existing coverage providing low-speed services; operators will not be willing to spend additional capital on new base stations to increase capacity, since doing so will likely lead to no increase in revenue. The only way to ensure that these areas are covered by high-speed and high-quality connectivity is to ensure that operators can roll out additional spectrum on existing sites. This additional spectrum will need to be in the UHF band to maintain the cell radius and make use of existing networks.

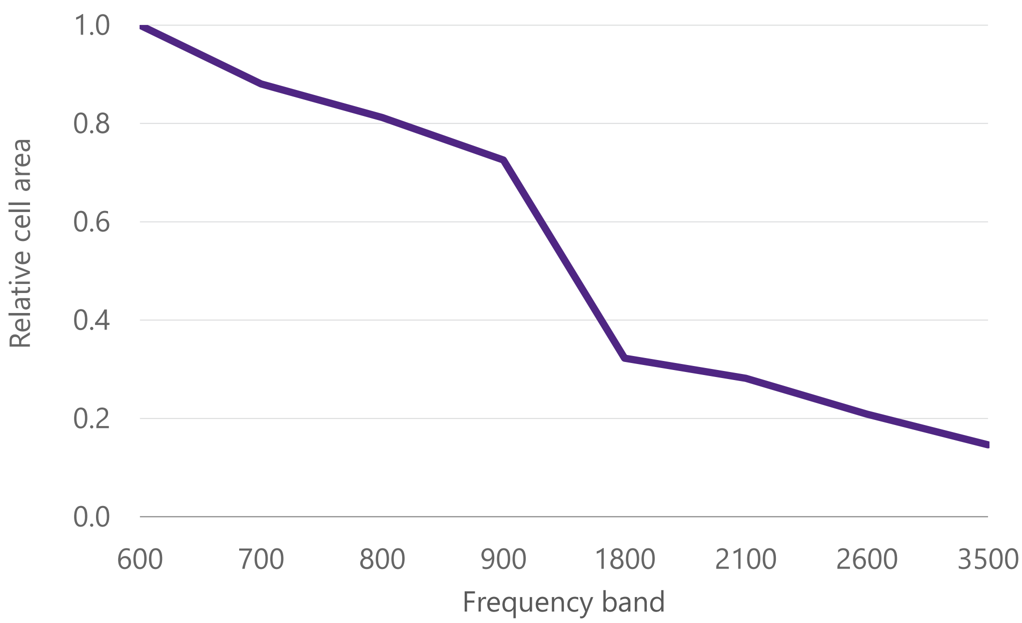
[76] These include a combination of IMT bands in the 700 MHz to 2.6 GHz range, 3.5 GHz and mmWave bands.
[77] GSA, Nokia, Automotive services enabled with LTE evolution for IoT.
[78] GSMAi, September 2020, Driving the digital revolution with improved mobile coverage. https://www.gsma.com/spectrum/wp-content/uploads/2020/11/Rural-Mobile-Coverage-Positions.pdf

2.5.1 Considerations on network planning

Path losses increase with frequency, due both to the smaller proportion of a wavefront intercepted by antennas of a given directivity, and because losses due to diffraction around terrain and obstacles will be higher, leading to more fragmented coverage in hilly terrain. Both factors imply that a more dense network infrastructure is invariably required to provide a coverage layer in higher frequency spectrum.

Although a halving in frequency, for example from 1800 to 900 MHz, can be shown to imply a doubling of coverage radius on the basis of free-space path loss (and consequently reducing the number of required sites by a factor of four), the real-world situation is inevitably more complex due to antenna considerations, available channel bandwidths, and so on. The best indication of the coverage attained at different frequencies would be to examine real-world deployment statistics, but this approach is challenging due to the use of hybrid network topologies implementing coverage and capacity layers at different frequencies. Detailed network simulations in specific environments can form a useful proxy, however. The figure below illustrates some results Plum has previously found from real-world analysis. The relative cell sizes at different bands is clear to see.

Figure 2.15: Relative cell coverage by frequency band in rural environment[79]



This need for low-frequency spectrum is echoed by operators.

- In South Korea, 5G networks are already well established using 3500 MHz spectrum, but in April 2020 KDDI announced a new network expansion using 700 MHz technology. The equipment manufacturer, Samsung, noted the use of 700MHz spectrum "will enhance KDDI's 5G network coverage, improving indoor and outdoor mobile experiences, and provide reliable 5G connectivity to users". The use of 700 MHz equipment was cited as a crucial step to be able to reach 90% population coverage.

- In Nigeria, in March 2021 MTN acquired an addition 10 MHz of spectrum in the 800 MHz band, stating "Through this acquisition, we will be better positioned to support the deepening broadband penetration

[79] Plum analysis

in the country. The added resources will also greatly impact our customers' experience providing even better internet connectivity".

- In the UK, in response to Ofcom's consultation[80] ahead of the 5G auction, BT/EE claimed that low "frequency spectrum would be crucial for providing 5G services, in particular eMBB (enhanced mobile broadband), service continuity in moving vehicles, IoT services and ultra-reliable and low latency communications (URLLC) It argued that the difference in good quality indoor coverage would be even more obvious as 5G mobile services were introduced, as customers would increasingly demand seamless connectivity using data intensive services indoors and deep indoors".

- In the same consultation, H3G argued that "ubiquitous coverage was the most important aspect of reliable connectivity, especially for massive IoT and critical communications. It claimed that 700 MHz was important for IoT given its use as a 5G coverage layer and that there were many IoT use cases that would require deep inbuilding and underground access, for which 700 MHz would be important".

This economic need for low-frequency spectrum in deep rural areas is true for basic mobile coverage, but it is true to a greater extent for high-speed and high-reliability connections. Even in rural areas where there is a case for providing some mobile coverage, it is more difficult to justify the greater spend needed to increase the performance of connections, particularly where low-band spectrum shortages would require more base stations to be installed. In order to meet certain performance levels, operators in this case would have two options:

- Install additional base stations using the low-band spectrum (namely, densification of the networks), which would increase costs and simply add more capacity at the same network quality; or

- Install additional base stations using mid-band spectrum, which would give a higher quality of service but may require more dense network deployment.

Neither of these would be economically viable because of the size of population in these areas; the second case would already have been discarded by the operator when designing the network, and the first would give the operator no additional revenue. Site densification in the same bandwidth only moderately improves performance. Thus, the only viable way of increasing capacity (and therefore improving performance) would be to add more low-band spectrum in the 470-694 MHz range to existing base stations.

This increased amount of spectrum would not only increase the capacity of the network, but would also improve the quality.

As described by Claude Shannon, the availability of additional bandwidth can be used to increase the coverage radius associated with a certain user experienced data rate, or to increase the data rates available at a certain distance from the base stations, or some combination of the two. In the latter case, additional RF bandwidth B increases the achievable channel capacity C as a linear factor.

Figure 2.16: Shannon channel capacity

$$C = B \ln\left(1 + \frac{S}{N}\right)$$

In a practical system, however, the maximum throughput for a given bandwidth will be capped by the spectral efficiency of the technology adopted. For the case of the 5G NR system, maximum throughput rates for different bandwidths and other system parameters are shown in the table below.

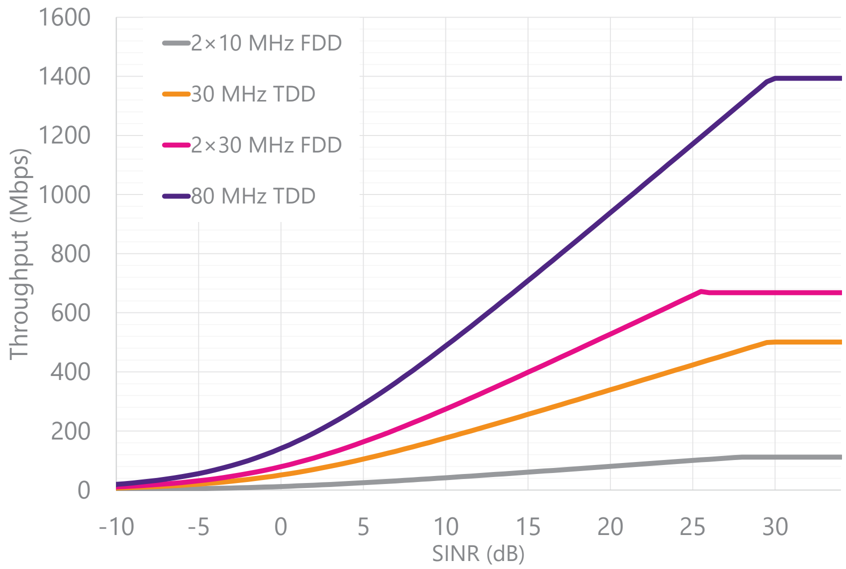
[80] See https://www.ofcom.org.uk/__data/assets/pdf_file/0020/192413/statement-award-700mhz-3.6-3.8ghz-spectrum.pdf

Figure 2.17: Maximum NR downlink throughput rates[81]

	2×10 MHz FDD	30 MHz TDD	2×30 MHz FDD	80 MHz TDD
Possible deployment	700 MHz	2.3 GHz	2.6 GHz	3.5 GHz
Numerology	0	1	1	1
MIMO layers	2	4	4	4
TDD factor (DL/UL)	-	80:20	-	80:20
Max throughput (Mbps)	111[82]	501	668	1,393

These are the highest downlink throughput rates that can be provided to a single user close to the base station. In practice the achievable bit-rate will vary throughout the cell as indicated by the curves in the table below.

Figure 2.18: Example single-user downlink throughput for different NR deployments[83]



There is therefore an obvious trade-off between higher potential bitrates and cell radius, and the continued need to maintain legacy 2G and 3G networks in many countries meaning there is limited bandwidth currently available in UHF bands. Thus, many operators may face difficulties in providing high broadband speeds in deep rural locations cost effectively. If greater bandwidth were available in the UHF band, this higher potential speed would be available over a much wider area, making it more economically feasible to serve these areas.

2.5.2 Improvements in technology

While the demand for Internet bandwidth increases at an exponential rate, we should not ignore the fact that technology improvements are themselves having a significant impact on the capabilities of networks. Following the first mobile data services available alongside 2G connections – with GPRS representing the first dedicated data service – there has been a steady increase in capability and speed.

[81] Source: Plum analysis based on 3GPP TS 38.306. Typical operator holdings at each spectrum band are used for reference; note that throughput is lower on low-bands and therefore larger bandwidth would be required to achieve the same outcome.
[82] This is likely to increase with 3GPP Release 17.
[83] Source: Plum analysis based on 3GPP TS 38.306.

While this improvement in technology is set to continue in the future, it is not changing at a rate fast enough to accommodate the changes in demand discussed in Section 2.2.

There are a number of further technological improvements that have been made to increase capacity and bandwidth. While these are expected to be deployed in the mid and high bands, rather than UHF spectrum, they can help supplement capacity needs for specific use cases in rural areas, such as smart farming, advanced manufacturing and 5G FWA, where necessary.

- **Active antenna systems**: In a traditional antenna, highly-directional beams can be generated by using arrays of small individual antenna elements (dipoles) combined so as to focus energy in a particular direction. This approach is often used to generate sharp beams in the horizontal and vertical planes to focus the energy where needed to avoid wasting energy above the horizon. The availability of cheap computing power has recently allowed these arrays to be reconfigured in real time, allowing:

  – Beamforming, to direct energy towards a single specific user, extending range for a given throughput.

  – Single-user MIMO: to create multiple 'data-pipes' between the base station and individual users, thus increasing throughput while requiring no more spectrum;

  – Multi-user MIMO, where different 'beams' target different users to increase cell capacity.

  The implementation of such active antenna systems requires the use of a large number of antenna elements, typically separated by distances of the order of a wavelength; making this technology enhancement suitable for mid and high bands. However, at UHF, a wavelength is around 0.3-0.4 m, and efficient active antennas become hard to accommodate without very large and expensive support structures which may not be acceptable in terms of visual impacts on the environment.

- **Very high bandwidth**: An aspect of 5G that has received a lot of attention is the ability to exploit frequencies (such as 26 GHz) that are an order of magnitude higher than those used by previous generations' cellular systems to date. The very high bandwidths available at these frequencies permit user data rates in excess of 1 Gbps, but path losses imply that cells are reduced, – typically only hundreds of metres or so, although in some cases signals have been found to reach larger ranges.[84] Due to its characteristics, the mmWave systems are envisioned to cover localised high capacity areas. Although the mmWave could be used where needed in rural areas, the high site density implied makes such frequencies unsuitable for wide area rural deployment.

2.5.3 Scarcity in the UHF band

The propagation advantages of sub-1 GHz UHF spectrum means they are the preferred choice for the coverage layer of public mobile services. These frequencies allow operators to provide the widest possible coverage across national boundaries and to improve deep indoor mobile coverage in a cost-effective manner. Hence, mobile operators have chosen to refarm their original UHF holdings where possible from 2G to 3G, and in some cases to LTE, to improve coverage while making more efficient use of scarce UHF spectrum.

Due to the number of existing subscribers and services that rely on 2G, 3G and LTE networks in the UHF band, it has not been feasible for operators to refarm significant portions of the 900 MHz or 800 MHz bands for 5G. In some cases the 700 MHz is already being used for LTE. Further, many early IoT or M2M devices, such as meters or sensors, require a 2G connection to send a small amount of data on an occasional basis. Some subscribers are still restricted to 3G devices, especially in poorer, more rural areas. Migrating these users can be a time-

[84] See for example https://spectrum.ieee.org/tech-talk/telecom/wireless/millimeter-waves-travel-more-than-10-kilometers-in-rural-virginia

consuming and costly process and decommissioning legacy networks requires detailed planning to avoid disruption to essential connectivity services.

New technologies such as Dynamic Spectrum Sharing (DSS) can help ease the refarming process. However, there is only around 200 MHz of sub-1 GHz spectrum which is shared by three or four operators in most markets. Thus, even if all the currently available UHF spectrum is refarmed for 5G in rural regions[85], this may not be enough to achieve the desired downlink user experience of 100 Mbps, as envisioned by the ITU[86], which is also a strategic objective for all households in Europe by 2025[87].

2.5.4 Lessons from previous network rollouts without sub-1 GHz spectrum

It is crucial that sufficient UHF spectrum is available for 5G networks. If operators are restricted to 2×10 MHz of 700 MHz spectrum in the near term,[88] then wide area networks in deep rural areas (and along long or non-major transport links) will be significantly limited compared to those in urban areas. Given the large areas that need to be covered, it would not be economically feasible for individual mobile operators to enhance rural network quality though network densification. Without adequate UHF spectrum, it could take a long time for good quality networks to be rolled out to the remaining areas, if they are ever rolled out at all.

The urban-rural gap can be seen from previous network rollouts.

When **3G networks** were first launched in the early 2000s, they were not allocated any additional UHF spectrum to facilitate the introduction of 3G, and in most countries across the world operators were allocated the 2100 MHz band. This band has poorer propagation when compared to UHF or even the 1800 MHz band, and it made network rollout expensive to cover hard to reach places or deep rural areas. As a result, 3G coverage was very limited for many years, with only urban areas covered. It was not until the liberalisation of the 900 MHz band that 3G coverage in rural areas was achieved in many countries.[89]

In the UK, the new entrant operator (Three) lobbied the regulator, Ofcom, for access to lower-band spectrum so that it could compete with other existing operators. Ofcom responded in two ways: first, they introduced a national roaming condition on one of the other operators so that Three's subscribers could use an existing 2G network when 3G was unavailable; and second, when Orange and T-Mobile merged to form one company in 2010, one of the competition remedies introduced was that Three must be given the opportunity to buy part of their lower frequency holdings[90].

Globally, the number of 3G subscribers grew steadily between 2003 and 2009, but following the rollout of UMTS900 networks (starting in Finland, France and Portugal in 2009) there was a faster rise in the adoption rate – as operators were able to provide much more extensive coverage.

At the time of **LTE network** launch, much of Region 1 had committed to clearing TV broadcasting from the 800 MHz band following analogue switch-off. In Germany, where 800 MHz was assigned in 2010, 4G coverage

[85] There is currently around 200 MHz of available UHF spectrum for mobile in most countries which could theoretically provide at a minimum of 2×25MHz per operator.

[86] ITU (2017). Report ITU-R M.2410-0. Minimum requirements related to technical performance for IMT-2020 radio interface(s). Available at https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

[87] The European Commission strategic objectives for 2025 includes access to connectivity offering at least 100 Mbps for all European households. See https://ec.europa.eu/digital-single-market/en/broadband-europe

[88] In many countries, spectrum in the 800 MHz, 850 MHz and 900 MHz bands would be needed to support a combination of 2G, 3G and 4G services potentially up to 2030 and beyond.

[89] European Commission (16 October 2009). Commission Decision 2009/766/EC on the harmonisation of the 900 MHz and 1800 MHz frequency bands for terrestrial systems capable of providing pan-European electronic communications services in the Community. Available at https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009D0766

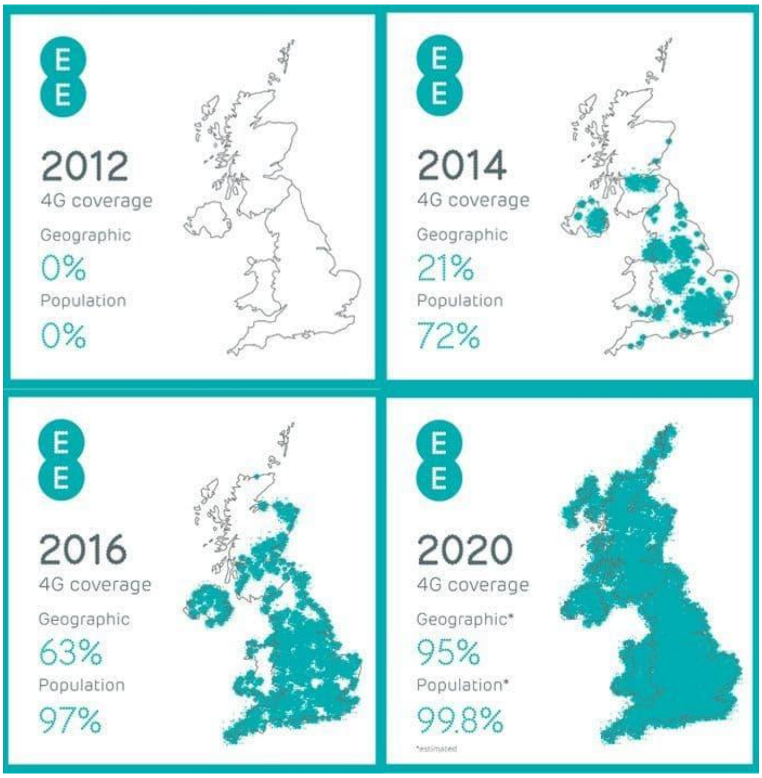
[90] The lower frequency holdings used by Orange and T-Mobile were in the 1800 MHz band, and not the sub-1GHz bands, but Three's argument of being disadvantaged by only having higher-frequency spectrum remained. At the time of the merger, when Three only had access to 2100 MHz spectrum, it covered approximately 75% of the UK population; by 2015, after gaining access to 1800 MHz bands this had increased to 95%.

based on 800 MHz quickly outgrew 3G coverage which was limited to 2100 MHz. In some other countries, however, by 2010, when LTE networks started to launch, this clearance process hadn't happened.

As a result, operators were forced to refarm part of their existing spectrum holdings to run LTE networks, with many choosing to use part of the 1800 MHz spectrum which was at that time reserved for 2G. Some operators, without access to 1800 MHz bands, were unable to launch LTE at first; others launched networks in a limited way.

By 2014, EE in the UK (formed from the merger of Orange and T-Mobile) had launched an LTE1800 network which covered 72% of the population, but only 21% of the geography of the country. Ofcom had carried out the 800 MHz (and 2600 MHz) award in early 2013, but the spectrum was not available for use until later that year. Once the 800 MHz spectrum was available, EE's geographic coverage increased quickly, tripling within two years.

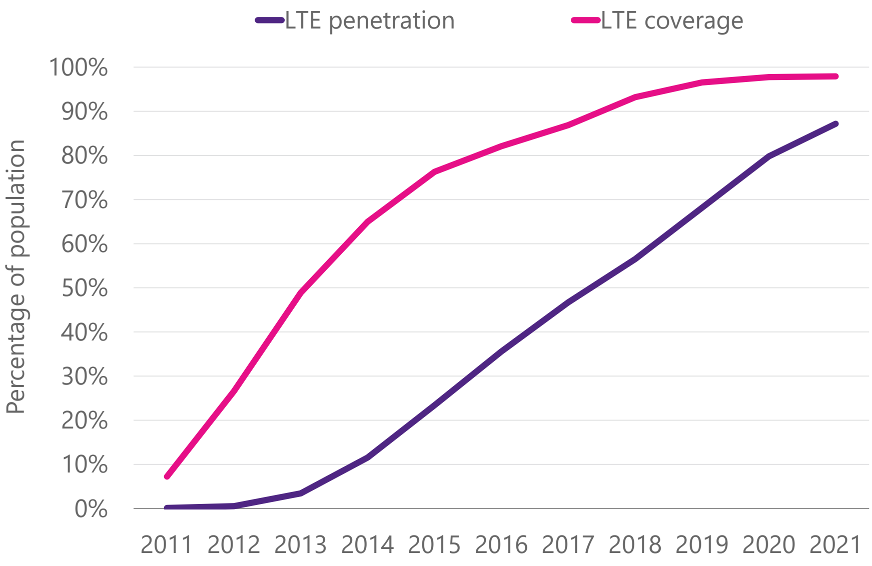
Figure 2.19: EE coverage maps over time[91]



A similar pattern was seen across Europe. LTE networks were slow to establish, with significant population coverage only being achieved once 800 MHz spectrum was generally available by 2014. Due to the low geographic coverage, LTE adoption was relatively slow at first, again, only starting to grow after 800 MHz spectrum was available.

[91] Source: https://www.choose.co.uk/news/ee-4g-uk-coverage-95-2020.html

Figure 2.20: LTE coverage and adoption across Europe[92]



Without the availability of low-frequency spectrum and coverage obligations, both 3G and LTE networks would likely have taken much longer to reach near-ubiquitous population coverage, if at all. This would have resulted in a more pronounced digital divide. A similar issue may arise with 5G networks, if there is not sufficient UHF spectrum to run a comparable service to that seen in urban areas. Furthermore, policy makers should also take into account spectrum requirements in low bands to ensure the future evolution of mobile networks beyond 5G.

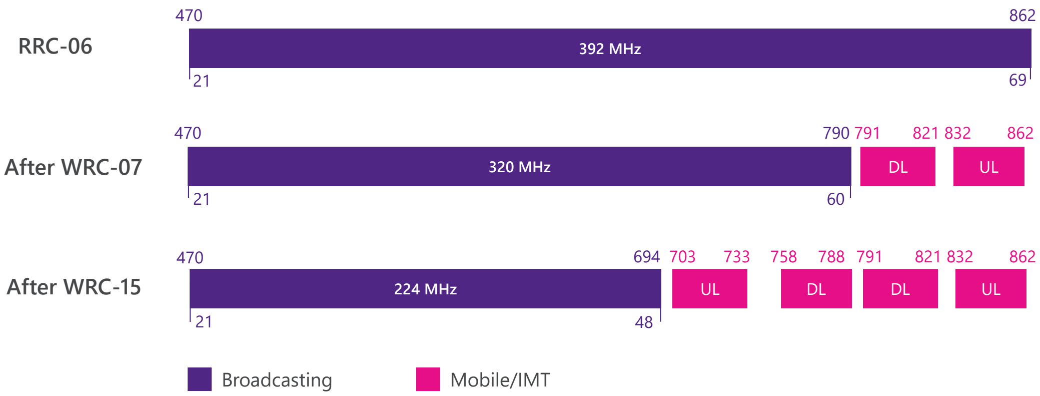
[92] Source: GSMA Intelligence.

3 The use of UHF by television broadcasting

Historically TV services have been distributed through over-the-air terrestrial broadcast networks which have primarily utilised the UHF band (470-862 MHz) though parts of VHF band have also been used in some countries. In the last two decades, the introduction of digital terrestrial television (DTT) and subsequent analogue switch-off (ASO), which has been completed in many countries across ITU Region 1,[93] has enabled more efficient utilisation of spectrum for delivering broadcast TV services both in terms of number of TV channels and the provision of high-definition (HD) services.

The transition to DTT has also facilitated the release of part of UHF spectrum for mobile broadband services – first, the 800 MHz band (791-821/832-862 MHz),[94] and then the 700 MHz band (703-733/758-788 MHz)[95] as illustrated in Figure 3.1. The result is that DTT services in many parts of Region 1 are currently operating in 470-694 MHz frequency range.

Figure 3.1: Changes in TV broadcasting spectrum (Region 1)



3.1 DTT services are well established

While DTT was first deployed in Europe in the late 1990s, most DTT networks in Region 1 were launched in the 2000s and early 2010s to replace analogue broadcast networks as part of the digital switchover (DSO) process. Terrestrial broadcast TV networks have traditionally played a key role in the delivery of public service broadcasting. This continues to be the case with DTT and the increased capacity of DTT networks has facilitated the introduction of more free-to-air public and commercial TV services, and in some cases pay-DTT.

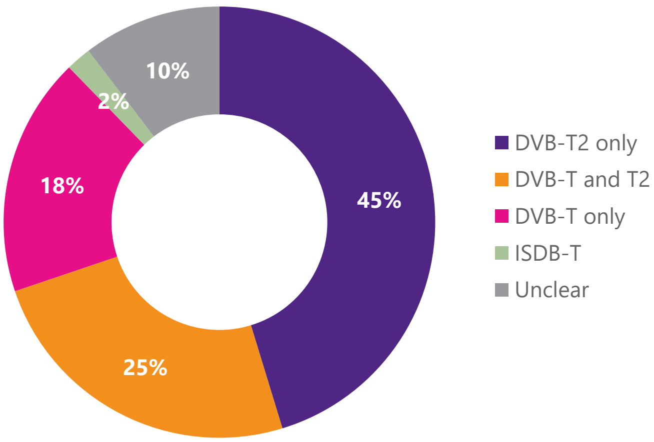
In Region 1 these are based mainly on the DVB-T transmission standard and its successor DVB-T2 as illustrated in Figure 3.2. The DVB-T standard was specified in 1997 and introduced widely in many European countries. In a typical European deployment, a DVB-T signal in an 8-MHz channel will carry data at between 20 and 25 Mbps which allows for up to nine SD linear broadcast channels.

Those countries that launched DTT services at a later stage have typically opted for DVB-T2 which was published in 2008. DVB-T2 offers higher modulation schemes, additional OFDM modes and new error correction

[93] A recent ITU survey on broadcast needs in the UHF band indicated that 73 out of 121 administrations in Region 1 have completed ASO as of 2020.
[94] EC Decision 2010/267/EU: "Commission Decision of 6 May 2010 on harmonised technical conditions of use in the 790-862 MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union"
[95] EC Decision 2016/687/EU: "Commission Implementing Decision (EU) 2016/687 of 28 April 2016 on the harmonisation of the 694-790 MHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services and for flexible national use in the Union"

mechanisms which allow spectral efficiency improvements of around 50% to 60% over DVB-T.[96] A single DTT multiplex (mux) using DVB-T2 and MPEG-4/H.264 coding could support up to 15 SD or four HD channels, or up to six HD channels if the newer coding techniques, such as H.265, are used.

Figure 3.2: DTT standards deployed in Region 1[97]



3.2 DTT is not necessarily an efficient use of spectrum

The network topology of broadcast TV networks is based on high power high tower (HPHT) networks for TV broadcast. The majority of the population is served from a relatively small number of towers often located on high ground and with mast heights of 100m or more. These transmit at very high power levels in the region of 20-100kW, and cover areas with a radius of 50km or more. In most countries a small number of such towers are needed. They are supplemented by relays – lower power transmitters that fill in coverage holes such as those that can occur in deep valleys and that extend coverage in rural areas. HPHT DTT networks typically offer between 95% and 99% population coverage. In some countries, DTT coverage reaches 99.9%.

DTT networks can be designed as single frequency networks (SFNs), multi-frequency networks (MFNs) or a mix of both. In MFNs neighbouring main transmitter sites broadcast on different frequencies to avoid destructive interference at the receiver.[98] In SFNs the same content is broadcast on the same frequencies in neighbouring cells. In order for receivers to correctly decode the transmissions, these need to be tightly synchronised and some redundancy inserted into the transmitted data to allow for propagation time differences between cells. Both SFNs and MFNs can provide regional or local TV services in which different coverage areas receive different content. For SFNs regional broadcasting would involve the use of different frequencies to mitigate interference to receivers in border areas – in these cases a spectrum reuse pattern of four or five is common.

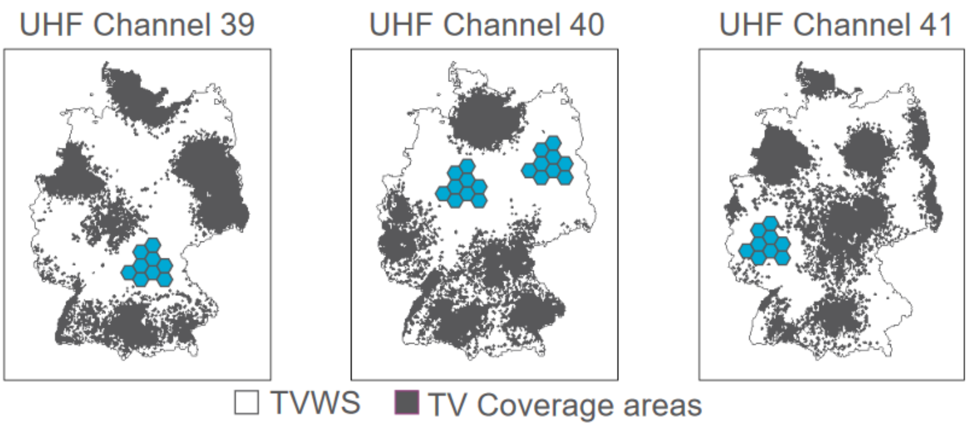
If there were 6 multiplexes required across a country, this would require 48 MHz of spectrum in a given location, but given the need for avoiding interference this would then require in the order of 224 MHz nationwide due to the frequency planning problem. Therefore, even where DTT provides good technical efficiency in terms of

[96] European Commission. Challenges and opportunities of broadcast-broadband convergence and its impact on spectrum and network use. Final study report by Plum and Farncombe. December 2014.
[97] Source: Responses to ITU questionnaire on broadcast needs in UHF band, Circular Letter 6/LCCE/104.
[98] A spectrum reuse pattern of four or five might be required. This effectively means that a quarter or a fifth of the available frequencies are used on any given mast.

bit/Hz/multiplex (based on very clean interference levels from frequency planning), this translates into poor spectrum efficiency when considering the total bandwidth required.

Therefore, while DTT standards are technically efficient, the characteristics of broadcasting networks as described above mean there are always large parts of the allocated UHF frequencies being left unused at a particular time and geographical location. These unused frequencies are termed "TV white spaces" (TVWS), and are illustrated in Figure 3.3 below. Some of these frequencies are used for programme-making and special events (PMSE), radio astronomy and weather observation purposes (wind profilers).

Figure 3.3: Example of TV white space in Germany[99]



Despite some interest during the early 2010s in using TVWS for the provision of wireless broadband services on an opportunistic basis through the use of geo-location databases, such initiatives failed to gain traction due to delays and a lack of certainty in the regulatory environment.[100]

3.3 Countries have a varying reliance on DTT

The number of national DTT muxes deployed or planned in the UHF band typically ranges from one to six. Figure 3.4 shows the breakdown of the number of national DTT multiplexes in Region 1 based on the responses from national administrations to the ITU's 2020 questionnaire on broadcasting.[101] The number of free-to-air DTT channels vary significantly but the number of national FTA services in most countries falls between three and 20, though in some countries there can be around 30 or more services available as shown in Figure 3.6.

In the different parts of Region 1, DTT services are generally more widespread across Europe (CEPT administrations) compared to Africa (ATU) and the Middle East (ASMG). On average, there are 18 national DTT services in Europe, compared to 14 in Africa and nine in the Middle East. There are significant differences within each region as well – for example in Europe, Belgium, Denmark, Estonia, Iceland, Netherlands and Norway have less than five national DTT services each while others such as Albania, Czech Republic, Finland, France, Italy, Spain, Ukraine and the UK have more than 20. See Appendix B.

Not all countries have regional or local DTT services though these tend to be common in larger countries. In those countries with such services, there are usually around one to six local or regional muxes in operation, though a few, for example, Greece and Italy, have significantly more. Pay DTT are also less common with

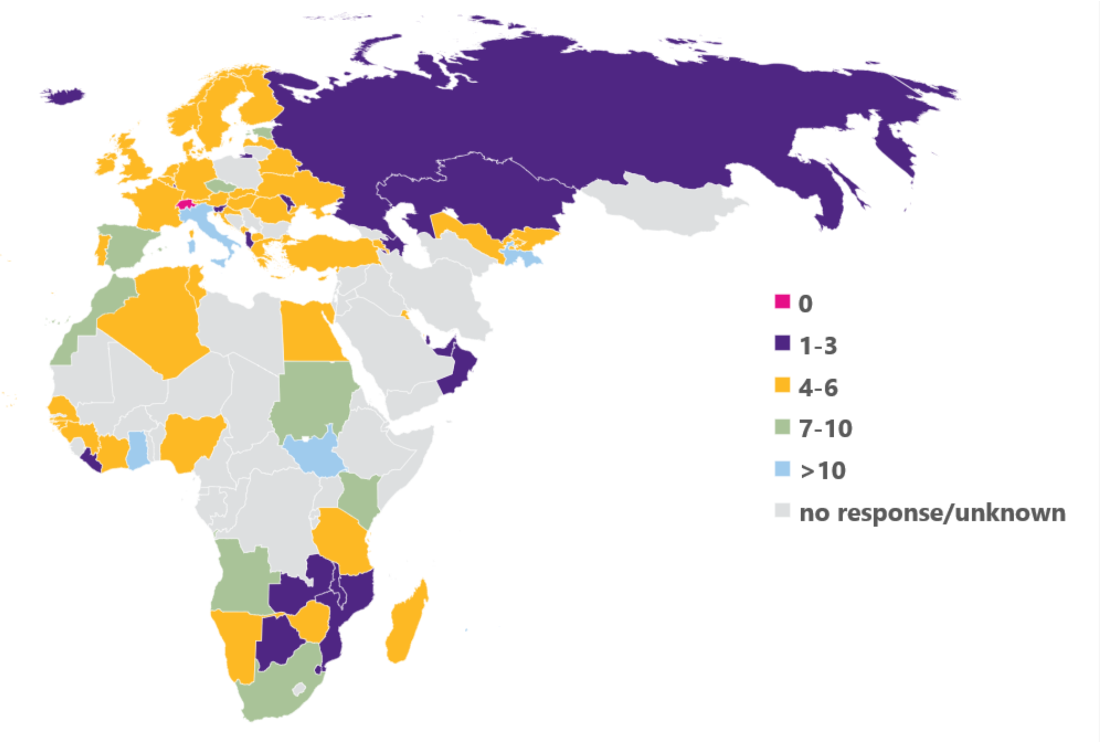
[99] Source: Dudda, T et al. (2012). How much TV White Space is there in Germany? Ericsson Research. Available at https://www.hs-osnabrueck.de/fileadmin/HSOS/Forschung/Recherche/Laboreinrichtungen_und_Versuchsbetriebe/Labor_fuer_Hochfrequenztechnik_und_Mobilkommunikation/Mobilkomtagung/2012/6_Torsten_Dudda.pdf

[100] Plum. Flexible spectrum access methods. Report for the UK Spectrum Policy Forum (17 October 2017).

[101] ITU (2021). Spectrum requirements for terrestrial television broadcasting in the UHF frequency band in Region 1 and the Islamic Republic of Iran. Report ITU-R BT.2302-1. See Annex 1. Available at https://www.itu.int/pub/R-REP-BT.2302

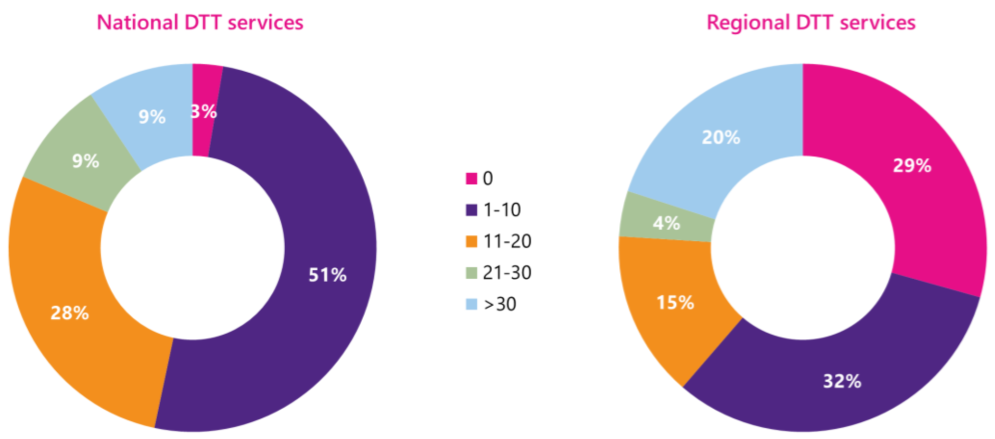
around half of the questionnaire respondents indicating that there were no pay DTT services offered. Generally the adoption of pay DTT services is low compared to other TV platforms.[102]

Figure 3.4: Number of national DTT muxes (planned/operational) in 470-694 MHz[103]



Based on the responses to the same questionnaire, more than half of Region 1 countries have less than 10 national and 10 regional FTA DTT services as shown in Figure 3.5 below.

Figure 3.5: Number of national and regional free-to-air DTT services in Region 1[104]

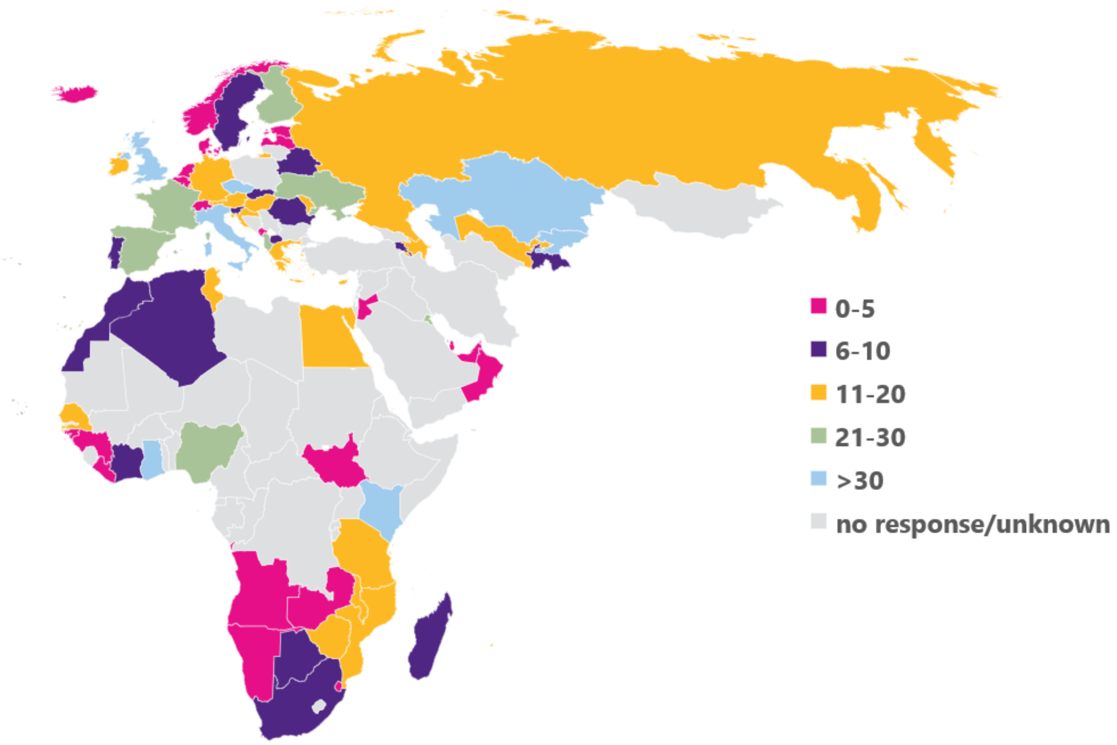


[102] For example, in the EU, households with pay DTT subscriptions account for less than 2% of total TV households as of end 2018. Source: European Audiovisual Observatory.

[103] Source: Responses to ITU questionnaire, Report ITU-R BT.2302-1.

[104] Source: Plum analysis of responses to ITU questionnaire, Report ITU-R BT.2302-1.

Figure 3.6: Number of national free-to-air DTT services[105]



This variation in the DTT service landscape across Region 1 is only partially reflected in the responses to the 2020 ITU questionnaire on spectrum needs for broadcast TV services in the UHF band. As illustrated in Figure 3.7 the majority of Region 1 administrations indicated that 224 MHz would be needed, which is the status quo. Some indicated greater than 224 MHz while a few – Egypt, Finland, Israel, Kuwait, Saudi Arabia, Slovenia and the UAE – indicated less than 224 MHz.

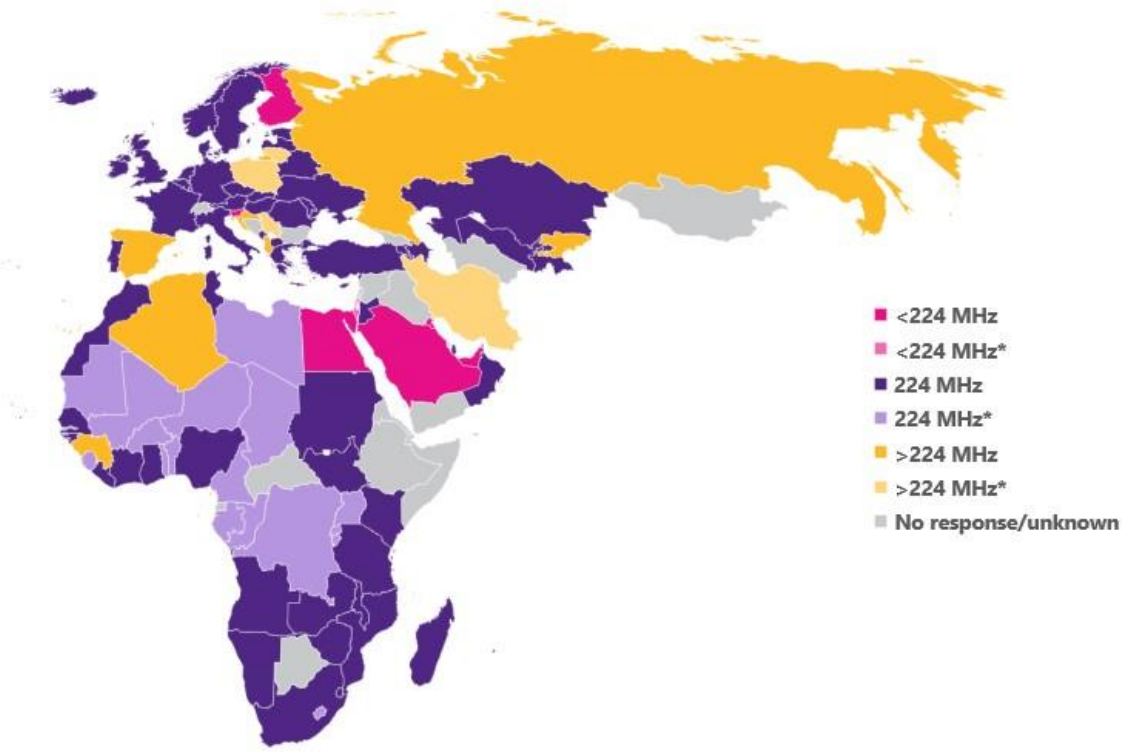
The general preference for status quo in the UHF is not driven by just specific demand within a country but also by the needs of neighbouring countries and the required reuse distances. For example, there is little DTT use in Belgium (with only one broadcasting group offering channels using one multiplex), yet their response to the questionnaire indicates that six multiplexes and 224 MHz are required. Similarly, there are relatively few broadcast channels in a number of African countries, meaning that retaining 224 MHz of spectrum for DTT would lead to significant inefficiency.

It should also be noted that a number of administrations did not respond to the 2020 questionnaire, mainly those in sub-Saharan Africa. For these administrations the responses to a similar questionnaire in 2013[106] were used to supplement the analysis. It is likely that the UHF requirements for these countries have changed since then due to market and technology developments.[107]

It is useful to compare this map in Figure 3.7 to those shown in Figure 3.4 and Figure 3.6. Most countries responding that there is a need for more than 224 MHz in fact have few services available; the majority of those countries making the least use of DTT have responded that the status quo is needed.

[105] Source: Responses to ITU questionnaire, Report ITU-R BT.2302-1.
[106] In 2013, ITU Working Party 6A conducted a similar survey of requirements for broadcasting to inform preparations for WRC-15 agenda items 1.1 and 1.2. That questionnaire is available as 6/LCCE/78, and the responses are summarised in Report ITU-R BT.2302-0 which is available at https://www.itu.int/pub/R-REP-BT.2302
[107] As many African countries have yet to complete analogue switch-off, the spectrum requirements may be somewhat overstated.

Figure 3.7: ITU survey on spectrum needs for broadcast TV services in UHF band[108] [109]



One possible reason for the homogeneity of the responses is the challenge of cross-border coordination procedures set out in the GE06 Agreement which governs the planning of DTT services in Regions 1 and 3.[110] The agreement sets out the conditions and guidelines for bilateral and multilateral coordination between broadcasting services in one country and other primary services, including as broadcasting or mobile, in another country. Given that the sub-700 MHz band has been harmonised across the whole of Region 1, any proposed change in the use of spectrum by an administration will involve significant technical assessment to determine how primary services in neighbouring countries might be affected and to seek their agreement before proceeding.

Plum, in an earlier study on the Arab region, had identified considerable scope to free up spectrum in the UHF band, including below 694 MHz, for mobile broadband through the transition to DTT.[111] The study had examined the number of DTT multiplexes needed to support existing linear TV services, taking account of upgrades from SD to HD. In most of countries, it was estimated that between one to four muxes would be needed and the estimated spectrum requirements are as illustrated in Figure 3.8. This shows that with adequate coordination among neighbouring countries, especially if the DTT requirements are roughly similar, then there is the potential for surplus spectrum to be made available for mobile or other uses.

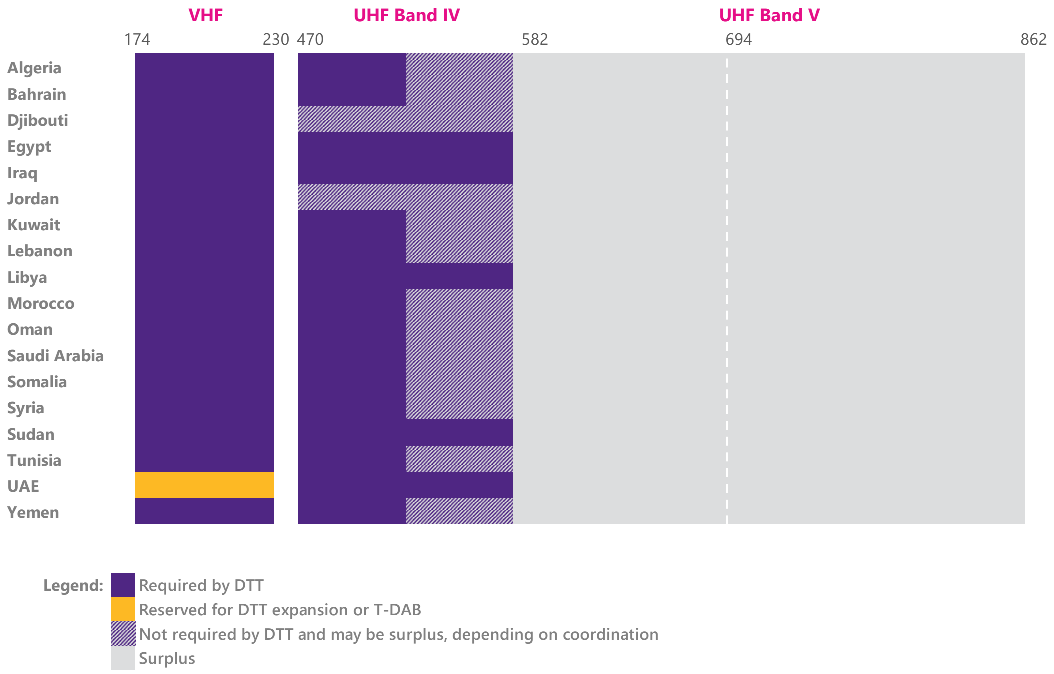
[108] Note: For administrations which did not respond to the 2020 questionnaire, it is assumed that the 2013 response is still valid. * refers to 2013 responses where 2020 responses are not available.

[109] Source: Responses to ITU questionnaires (2020).

[110] ITU (2006). Finals acts of the Regional Radiocommunication Conference 2006 for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06).

[111] Plum (April 2015). Terrestrial broadcasting and spectrum use in the Arab states. Report for GSMA. Available at https://plumconsulting.co.uk/terrestrial-broadcasting-and-spectrum-use-arab-states/

Figure 3.8: Estimated spectrum requirements for DTT in the Arab region[112]



As shown in Figure 3.4, there are a number of countries across Region 1 with less than four national DTT muxes planned or in operation, suggesting that future DTT needs could well be accommodated with less than 224 MHz. Thus, there may be opportunities to make more efficient use of the available UHF spectrum with sufficient planning by national regulators, taking account of cross-border coordination.[113]

3.4 Alternative TV technologies are increasing in use

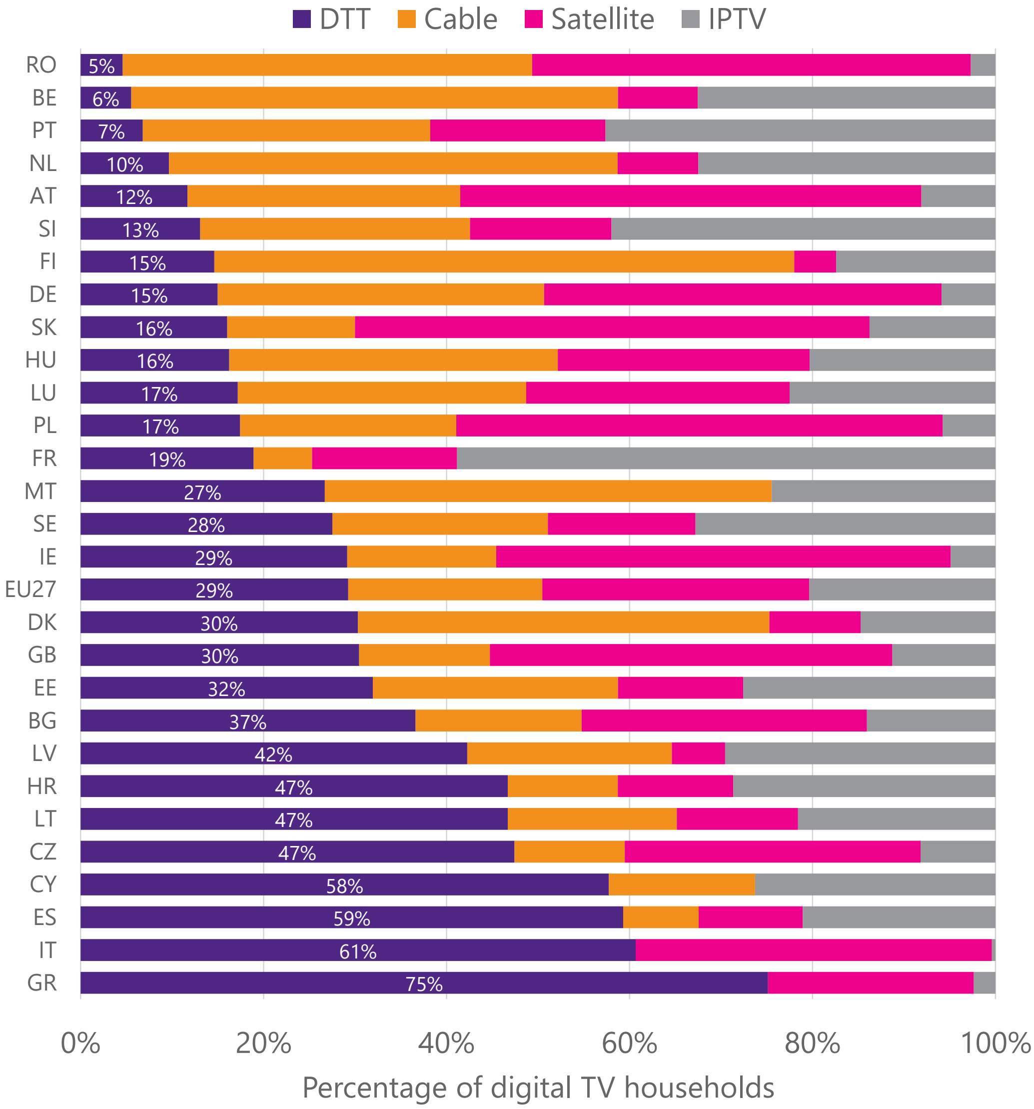
DTT is one of several means to deliver audiovisual content. Alternative technologies include cable, satellite (DTH) and broadband (IPTV and OTT). When compared to other methods of broadcasting, DTT has some significant disadvantages. In particular, the number of channels that can be carried by DTT is significantly lower than the number available to be broadcast by cable, satellite, or over IP delivery. However, the low cost of DTT technology for consumers means that it remains a common method of accessing content.

In all countries multiple options will be available to consumers although the coverage of these options tends to vary depending on country-specific circumstances. In general satellite TV tends to be most widely available across Region 1, while DTT is also widely deployed with coverage of 90% or higher in many countries.[114] The extent of cable and fixed broadband infrastructure (for the provision of cable and IPTV services) tends to be more varied across markets and is dependent on various factors including geography, policy and regulation.

There is huge variation across the EU in terms of digital TV reception as illustrated in Figure 3.9 below. In Africa there is generally greater reliance on terrestrial broadcast TV distribution compared to Europe as fixed infrastructure tends to be less developed.

[112] Source: Plum (April 2015). Terrestrial broadcasting and spectrum use in the Arab states.
[113] This could be done as part of the DTT planning process for countries which have yet to complete the DSO/ASO process, or as part of the renewal of multiplex licences.
[114] Though in the case of some countries which have only recently deployed DTT, services are yet universally available.

Figure 3.9: Primary TV set platform market share, 2019[115]



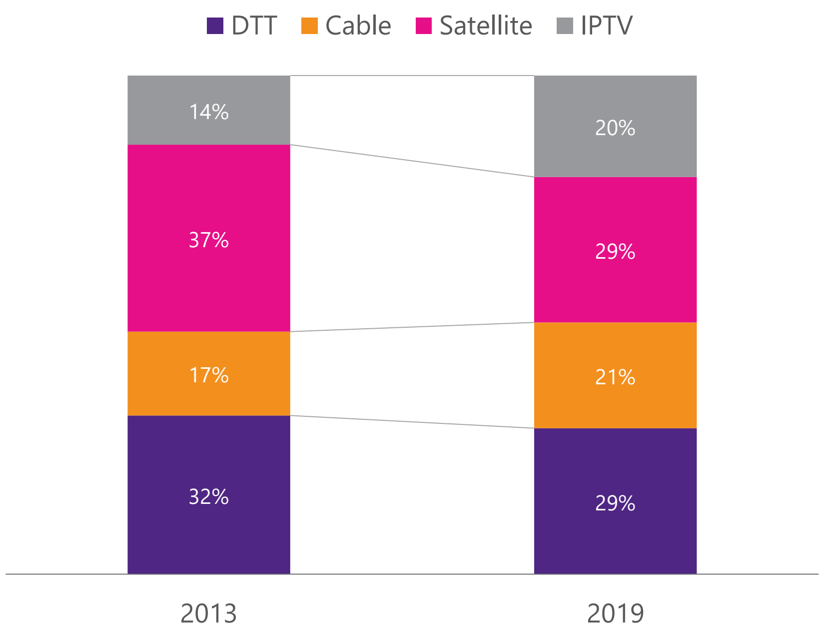
The DTT platform is designed primarily for the provision of linear TV services, although it is possible for DTT to be combined with on-demand services and interactive features through connected TVs and set-top boxes.[116] Cable and satellite TV platforms, while originally developed for delivering subscription-based linear TV channels, have innovated rapidly in recent years through integration with broadband and IP-delivery systems which are able to support VOD and other online content, 4K/HDR technologies and smart features such as voice control, data-driven personalisation and recommendation systems. IPTV, by its nature, relies on broadband to deliver content and is thus well-placed from a technology perspective to support both IP multicast for linear TV and unicast VOD services. It is widely recognised that IP-based distribution of media will become the norm in the digital media landscape and this is reflected in the pace of technical innovation and industry investment. In this light, the DTT platform may be less flexible compared to other technologies in terms of adapting to future developments and evolving consumer needs.

[115] Source: European Audiovisual Observatory
[116] For example, through technical standards such as MHEG-5 (Multimedia Hypermedia Expert Group) and HbbTV (hybrid broadcast broadband TV).

3.5 There is a general trend away from linear viewing

The growing capability and availability of both fixed and mobile broadband infrastructure in recent years has allowed the delivery of high-resolution audiovisual content on a large scale. This is partly reflected in the increased penetration of IPTV services. Among digital TV households in the EU, DTT's share among primary TV sets is 29% which is a slight decline from 32% in 2013. Over the same period, the share of IPTV has picked up significantly while satellite's share has fallen to the same level as DTT.

Figure 3.10: Primary TV set platform market share in the EU, 2013 vs 2019[117]



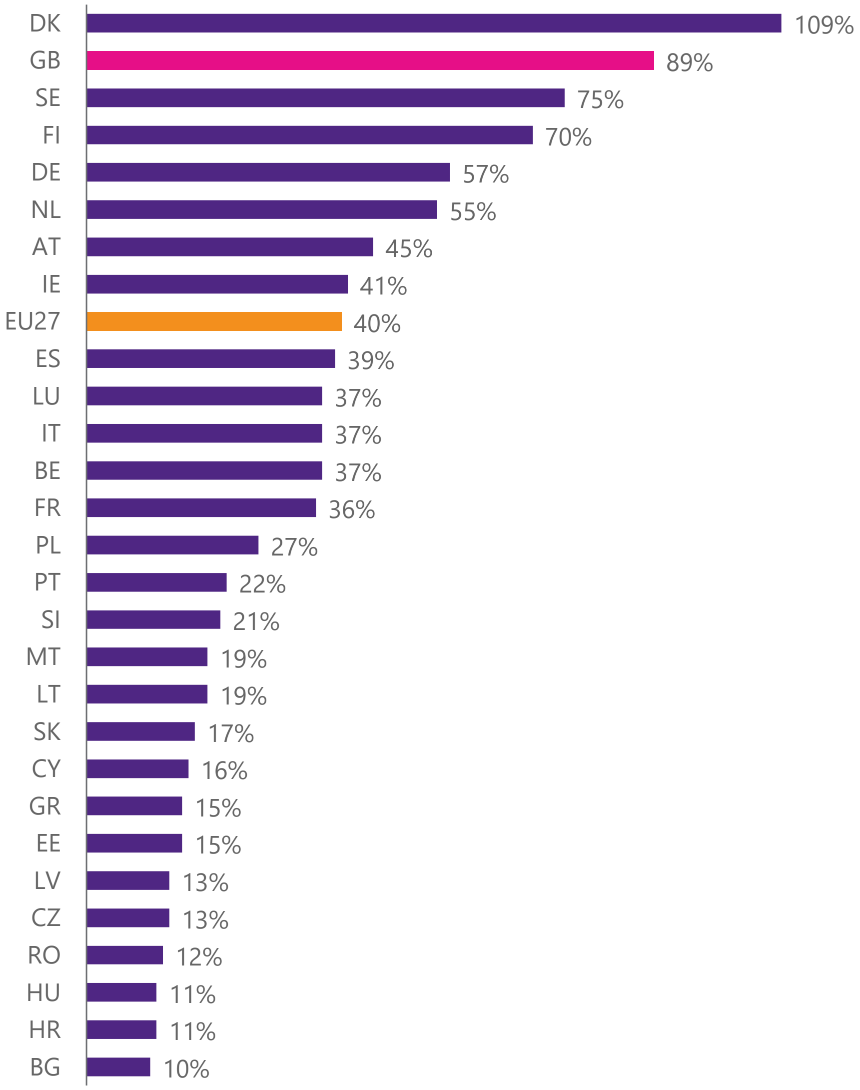
More significant though, is the emergence of new classes of online video services including video-on-demand (VOD) services, such as Netflix, Disney+ and Amazon Prime, and video-sharing platforms (VSPs), such as YouTube, Dailymotion and Twitch. These are sometimes labelled broadly as over-the-top (OTT) services which are delivered directly to users over the Internet, instead of via broadcast, cable or satellite transmission networks. These services typically feature easy-to-navigate user interfaces and rely on audience data to offer personalised and curated viewing recommendations. By the nature of their IP-distribution mechanism, these services tend to be global or regional in their operations.

The adoption of these online media services has grown rapidly, fuelled by the proliferation of connected devices, such as smartphones, smart TV sets, games consoles and tablets. A highly competitive mobile sector with attractive pricing and generous data packages by mobile service providers, as well as reductions in fixed broadband prices in recent years, have boosted growth in adoption and usage. The handling content within networks has also been aided by the rollout of locally-based content delivery networks (CDNs) and increased use of edge caching for regularly accessed content has improved delivery performance.

While these online video services are not direct substitutes for linear broadcast TV and are today often consumed in addition to traditional free-to-air and pay TV services, their popularity and rising usage is not in doubt. Across the EU, subscriptions to VOD services (SVOD) have grown from 10.4 million in 2014 to 81.3 million in 2019 at a CAGR of 51%.[118] While there is significant variation in terms of the level of adoption as illustrated in Figure 3.11, the growth trend is clear across all EU markets.

[117] Source: European Audiovisual Observatory, Plum analysis
[118] According to estimates by the European Audiovisual Observatory.

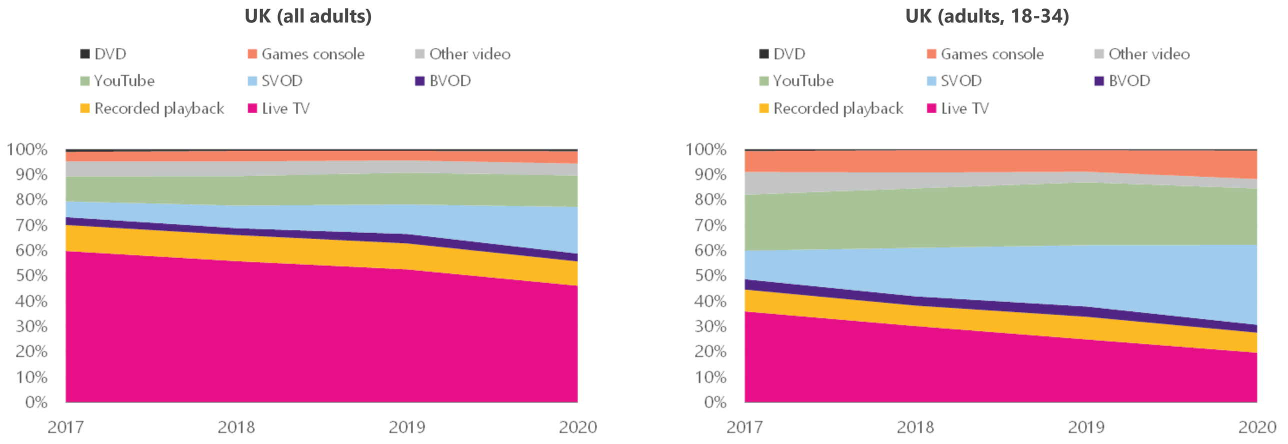
Figure 3.11: SVOD household penetration in EU, 2019[119]



In many countries time spent on linear broadcast TV still accounts for a significant amount of media consumption. However, online VOD and VSP services are gaining an increasing share of audience viewership. The trend tends to be stronger among young audiences (below 35) but is growing across the board as shown in Figure 3.12. Generally, viewers are not watching less television content, but they are watching it in a different way – on-demand with OTT services, and SVOD in particular, capturing a rapidly growing share of viewing time. While market dynamics and consumer preferences will differ across Region 1, the general shift towards online services and non-linear media consumption viewing is a clear development and will gather pace in the coming years. Linear TV will still play an important role, particularly for live news, and major sports and cultural events. For instance, during the initial stage of the Covid-19 pandemic, viewership of linear news programming grew across all age groups.[120]

[119] Source: European Audiovisual Observatory, Plum analysis
[120] Source: EBU (September 2020). Covid-19 Report. Public Service Media: Supporting Society Through Coronavirus. Available at https://ebu-reports.cdn.prismic.io/ebu-reports/fea30549-b542-4368-9892-cede720394a7_EBU_COVID-19_REPORT_2020_EN.pdf

Figure 3.12: Average share of total video viewing time by service/platform, UK[121] [122]



For broadcasters, the challenges are manifold. For public service broadcasters the decline in the traditional TV audience and the fragmentation of audiences across multiple services, platforms and modes of content consumption affects their ability to sustain high levels of reach, impact and value to audiences which is core to meeting the objectives of public service media, such as universality of access and appeal, delivering public value and promoting citizenship. For commercial free-to-air broadcasters and also pay-TV operators, the shift online is putting huge pressure advertising and subscription revenues.

3.6 The future demand for DTT is unclear

A key strategic question for broadcasters in this increasing competitive market environment is that of distribution. While TV viewing is as popular as ever, the growing number of potential viewing platforms means that DTT is facing ever-increasing competition for viewers. According to Ofcom research, 42% of adults consider online video services to be their main way of watching TV and film, and 38% of SVOD users say they can imagine not watching broadcast TV at all in five years' time.[123] In a recent interview Carolyn McCall, chief executive of UK broadcaster ITV, remarked that "*within the next decade TV will be distributed on the Internet, not through DTT*".[124]

This transition has already occurred in some markets. In Belgium (Flanders), the public broadcaster VRT ceased DTT transmission in December 2018 due to "radical changes in media use in recent years".[125] It was noted that fewer than 45,000 Flemish-speaking people (less than 1% of the population) were using DTT and the service was costing more than €1 million annually in transmission costs. Similarly, the Swiss public broadcaster SRG also shut its DTT network at the end of 2019 as part of a cost cutting move. In announcing its decision, SRG had noted that the reach of its DTT service was less than 2% of households and DTT was primarily used by secondary TV sets.[126] On the pay-TV side, Italian broadcaster Mediaset ceased its subscription DTT service in June 2019, shifting the service over to its OTT platform,[127] though its free-to-air services remain on DTT. In Lithuania, the

[121] Notes: The 'games console' category may include viewing of various OTT services, such as BVOD, SVOD and YouTube. Ofcom estimates of total audio-video viewing. Modelled from BARB, Comscore and Touchpoints data

[122] Sources: Ofcom Media Nations 2020. Available at https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/media-nations-reports/media-nations-2020

[123] Ofcom (27 February 2020). Small Screen: Big Debate–a five-year review of Public Service Broadcasting (2014-18). Available at https://www.ofcom.org.uk/__data/assets/pdf_file/0013/192100/psb-five-year-review.pdf

[124] BBC Radio 4. The Media Show. Interview with Dame Carolyn McCall. 11 February 2021. https://www.bbc.co.uk/programmes/m000srqq

[125] https://www.vrt.be/vrtnws/nl/2018/05/17/vrt-stopt-eind-dit-jaar-met-uitzenden-via-dvb-t/

[126] https://www.digitaltveurope.com/2018/09/06/srg-to-shut-down-swiss-digital-terrestrial-network/

[127] https://www.broadbandtvnews.com/2019/05/01/mediaset-premium-drops-dtt-distribution-goes-ott/

leading pay-TV provider Teo LT (owned by Sweden's Telia) phased out DTT in September 2018 and replaced it with OTT service delivered over its LTE network.[128]

For Belgium and Switzerland, it should be noted that the main distribution technology in these two markets has historically been cable and this has gradually been upgraded to IPTV in recent years. Cable and IPTV serve more than 90% of households while DTT's market share has always been around 5% or lower.

Most broadcasters are already adapting their digital strategies and focusing resources towards developing their online media players and service offerings to introduce more interactive features, personalisation on-demand content and personalised user experiences. In some cases this has also involved reducing the number of linear TV channels or moving them online to cater to the changing audience habits. In the face of declining broadcast TV audiences and advertising revenues, DTT distribution, with its fixed cost structure, may become prohibitive particularly for smaller portfolio channels.[129]

Against these changes, however, many other markets still rely heavily on DTT for television broadcasts, particularly in markets where this has historically had a high market share. Across the EU, the TV market landscape varies significantly as shown in Figure 3.9 above. In some large markets such as Italy and Spain, DTT penetration and usage remain high and this may continue into the 2030s. Even in markets where the demand for linear TV is declining, certain audience segments, such as the older viewers and low-income households, may still be dependent on DTT. Thus, DTT will continue to have an important role in ensuring the universality and accessibility of public service broadcasting. This means there will still be demand for DTT capacity in some markets at the end of this decade and beyond, though the level of demand is likely to be much reduced in many countries.

3.6.1 5G LTE-based broadcast and NR-based multicast/broadcast

Aside from DTT and cellular mobile services, another form of wireless distribution of audiovisual content is through mobile broadcast standards. The mobile and broadcasting industries, through the 3GPP standards body, have been working together for some years to add broadcast-specific functionality to cellular standards. Although 4G/LTE includes an FeMBMS (Further Evolved Multimedia Broadcast Multicast Services) mode in Release 14, which, in principle, allows dedicated broadcast-mode operation, this is constrained in many parameters, including the permissible network topologies and by the absence of support for MIMO. The recently frozen Release 16 provides further radio access enhancements including a larger and more flexible cyclic prefix to allow either high-speed operation or greater inter-site distances with 'LTE-based 5G terrestrial broadcast'.

A new Release-17 3GPP work item was approved in March 2021 to introduce the necessary features for LTE based 5G terrestrial broadcast (5G Broadcast) to operate in the portion of UHF spectrum allocated to broadcast systems in different regions of the world, including the addition of carrier bandwidths of 6, 7, and 8 MHz.[130] The spectrum-related aspect of this work item is to start from March 2022. Release 17 will add support for 5G NR multicast and broadcast support but the features are primarily for small scale and single-cell deployments and not large scale SFNs or receive-only devices.

The EBU has published a recent technical report[131] which summarises these developments. Several public service broadcasting organisations around the world are considering LTE-based 5G terrestrial broadcast. Trials and

[128] https://www.digitaltveurope.com/2018/08/07/telia-lithuania-begins-shutdown-of-dtt-following-lte-4g-tv-launch/

[129] For example, in Germany public broadcasters ARD and ZDF closed down linear TV channels EinsPlus and ZDFkultur in 2016 as part of the formation of the online youth content network Funk. In France, France Televisions has launched a new digital service Okoo aimed at children aged 3-12, with a view to shutting down the France 4 channel. In Denmark, Danmarks Radio has moved DR3 and DR Ultra to its DRTV streaming service while shutting down DR K).

[130] Available at https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_91e/Docs/RP-210907.zip

[131] EBU (29 May 2020). 5G for the Distribution of Audiovisual Media Content and Services. Tech Report 54. Available at https://tech.ebu.ch/publications/tr054

studies are being carried out, for example in Austria[132] and Germany,[133] to assess the performance and to define the network and frequency planning parameters for LTE-based 5G terrestrial broadcasting technology. The potential use cases include in-car media services, live streaming, emergency broadcasting, and automotive applications such as enhanced traffic information, map updates and car firmware updates.[134] [135]

For LTE-based 5G terrestrial broadcast to meet these use case requirements with near-universal coverage, the network topology would need a combination of conventional high-power high-tower (HPHT) broadcast and low-power low-tower (LPLT) mobile transmitters for mobile reception scenarios. For 5G Broadcast to offer a comprehensive TV experience, such a system would require the tight integration of linear TV with non-linear (on-demand) video content, combining the online service offerings of public service broadcasters like the BBC iPlayer, with OTT services like Youtube or Netflix. The 5G Media2Go[136] trial by the public service broadcaster SWR in the south-west of Germany, which involves stakeholders from broadcasting and mobile sectors, combines these elements for in-car media and entertainment. Collaboration between broadcasters, mobile network operators and stakeholders across TV and video value chain will be required to investigate and address issues around business models, infrastructure sharing and spectrum use.

At this stage it is unclear how this technology will evolve. The choices and outcomes, and by extension the future use of UHF spectrum, are likely to vary across broadcasters and countries depending on consumer behaviour, future technology developments, commercial imperatives, public policy and national objectives.

132 https://www.broadbandtvnews.com/2020/11/29/ors-5g-broadcast-is-the-future-of-television-but-challenges-remain/
133 https://www.broadbandtvnews.com/2020/10/01/swr-launches-5g-broadcast-trial-for-in-car-use-in-germany/
134 Dimitrakopoulos, N (10 December 2020) 5G Broadcast for Automotive. Presentation at ITU Workshop on Vehicular Multimedia Implementation. Available at https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20201210/Documents/Nik%20Dimitrakopoulos.pdf?csf=1&e=mbWAl9
135 Future Forum (November 2020). Use Cases of 5G Broadcast Technology. White Paper. Available at http://www.future-forum.org/dl/201126/whitepaper/70O1.pdf
136 SWR 2020 https://www.swr.de/unternehmen/kommunikation/pressemeldungen/swrunternehmen-swr-broadcast-projekt-2020-102.pdf

4 The use of UHF by other services

Mobile telecommunications and TV broadcasting are not the only users of UHF spectrum frequencies. In this section we consider other potential users, and how their spectrum needs must be taken into account when deciding on the future of the UHF bands.

4.1 PMSE

PMSE – Programme Making and Special Events – is a category of users who rely on UHF spectrum (and other bands) for operating private equipment, generally not part of a wider network. This includes handheld transceivers ('walkie talkies'), wireless microphones, in-ear monitors, and other transmission equipment used for internal production. Video transmission for PMSE is usually carried on a reserved band at 2010 MHz – 2025 MHz, meaning that the primary use for UHF is audio transmission.

The requirements for PMSE spectrum depend heavily on each individual use case. In 2017, the EU's Radio Spectrum Policy Group (RSPG) stated:

> **“the RSPG is of the view that due to the local and temporary nature of PMSE, especially for peak demand situations, requirements are best addressed on a case-by-case basis at a national level using the "tuning range concept" developed by CEPT.”**

A "tuning range" as defined by CEPT (the European Conference of Postal and Telecommunications Administrations) is a range of frequencies over which radio equipment is envisaged to be capable of operating. Within this tuning range the use in any one EU Member State of radio equipment will be limited to the range of frequencies identified nationally (if any) within that country for PMSE, and will be operated in accordance with the related national regulatory conditions and requirements. This therefore gives individual countries flexibility over how spectrum is used for PMSE, while providing equipment manufacturers with certainty over which bands should be supported.

Further, RSPG noted:

> **“Pre-existing constraints in Member States' national circumstances adds a further dimension and challenge to the adoption of EU-wide co-ordinated policy approaches. This is due to national differences in PMSE demand, but also due to different use in many of the frequency bands that PMSE shares with. Apart from the harmonised baseline for Member States the use of PMSE equipment is not fully harmonised across the Member States due to differing national PMSE requirements and divergent national frequency plans. PMSE stakeholders that operate internationally have a strong preference for equipment which may be operated across multiple countries”**

The allocation of spectrum for PMSE was therefore left for individual countries to decide on, but a 2014 EU Decision set a baseline of 60 MHz of spectrum to be available for PMSE use in each Member State; other countries in Region 1 have a less defined allocation. It must be noted, however, that the exact location in the band for this 60 MHz is not defined, and in fact can vary within a country, meaning that regulators can assign PMSE spectrum within television broadcasting bands in areas where it is not being used – known as interleaving.

For example, Sky UK has large recording studios in Osterley, in South West London. This area is served by the television transmitting station at Crystal Palace, although it would also receive some signals from Hemel

Hempstead, Reigate, and Guildford[137]. The frequencies used by the Crystal Palace transmitter are UHF channels 22, 23, 25, 26, 28, 29 and 48, meaning that Sky UK is able to use PMSE equipment tuned to any other channel, as long as it is able to block out interference from other transmitters.

It should be noted that PMSE use typically is very locally confined, either to fixed production locations like studios and theatres, or even sparse in time in event locations. Typically, intense PMSE use is required in densely populated areas and less in rural.

4.1.1 PMSE use will continue to grow over time

The overall demand for PMSE is difficult to define, given the distributed nature of its use. While there are many millions of devices across the world, the number in use at any one time is significantly lower – and the number in use at any specific location is a fraction of this. Rather than considering an overall trend is usage, we should consider the peak demand in defined locations. RSPG noted:

> **“In assessing the spectrum requirement for PMSE, it must be borne in mind that PMSE demand is mainly time and location specific. Meeting peak demand at large events only becomes acute if spectrum at both the time and at the location it is required is difficult to supply. It therefore does not automatically follow that a greater number of large events over the course of a year – as has been the trend – presents any more of a challenge for PMSE spectrum availability. In the context of large events there may be also variations between spectrum needs for each type of application in use.”**

To determine spectrum requirements, therefore, it is important to consider the type of event which would use the largest number and the greatest bandwidth of devices. Typically, this is assumed to be a live music or theatre event, with multiple wireless microphones and other transmission required.

Although the number of such events is increasing over time, this does not change the key dimensioning factor for determining spectrum demand – the peak number of devices used at a single event. The number of devices is growing, but at a slow rate, as traditionally wired devices are replaced by wireless options.

4.1.2 Technology improvements are reducing spectrum constraints

Wireless microphones have been the main driver of PMSE demand over the last few decades, with performers moving from wired to wireless devices providing them with greater freedom on the stage. However, it is now rare for wired microphones to be used at such an event, meaning that there is unlikely to be a significant growth in spectrum demand for wireless devices going forward since there is no further substitution required. Instead, it is possible that, as analogue wireless microphones are replaced by digital devices[138] (which can be smaller with lower power requirements), spectrum demand may fall.

As well as this move from analogue to digital for a large number of devices, the spectrum efficiency of each type of device is itself improving. The RSPG noted in 2017 that newer equipment was capable of an increase in spectrum efficiency of:

- 2.5 times the typical existing level for analogue devices, and

[137] An interactive map can be viewed at https://ukfree.tv/maps/freeview
[138] In some cases the use of digital equipment is undesirable, particularly where latency is a major consideration – a performer who wishes to have an in-ear headset relaying back their performance typically demands an analogue solution.

- 3 times the typical existing level for digital devices.

Although these figures represented the performance of the most capable (and expensive) equipment available, technology improvements will ensure that eventually all users will have access to these devices. There could, therefore, be a significant reduction in spectrum needs for PMSE use. However, this may take some time to manifest, since older equipment will need to be replaced and this could be costly for users.

4.1.3 PMSE use can often be carried over 5G

As well as the potential reduction in spectrum demand described above, it is possible that some PMSE use could be moved to 5G technologies, which would then coexist alongside public networks. The use of network slicing on 5G systems allows the traffic of certain users to be prioritised on the network, meaning that an appropriate level of service quality could be maintained; further, the low latency objectives of 5G technology would make this system ideal for many existing PMSE users.

In order for this use of technology to happen, users would need to have confidence in the reliability and performance of 5G networks, which in turn would require significant investment from network operators. The use of small cells at both C-band and mm-wave levels would be needed to provide complete coverage, and this may be costly for some use cases.

Nevertheless, a number of regulators such as ARCEP in France and Traficom in Finland have examined how mm-wave technology could be used in arena venues. Further, a consortium of equipment manufacturers and users in Germany[139] has been carrying out extensive research on the requirements of PMSE and how this can be carried over cellular technologies. The white paper[140] concludes that an integration of PMSE in the 5G ecosystem is possible, but it will require extensive business modelling and cooperation between stakeholders. The possibility of technology replacement is reinforced by research by Nokia and Sennheiser in another white paper[141].

4.2 Radioastronomy

Radioastronomy is the study of space by monitoring electromagnetic radiation which has been emitted from celestial bodies. This branch of science dates to 1932 when signals from space were detected during a study of interference in standard radiocommunication systems. Since then directional antennae have been used to study the location and type of radiation to further the understanding of the universe.

Signals from space are typically very weak and require large signal gain antennae to detect. This means that any other use of the same radio band can impede the ability to measure these signals. As a result a number of spectrum bands have been historically assigned to be left clear for radioastronomy, including the 606 MHz – 614 MHz band within UHF. In the UK, for example, across the sub-700 MHz UHF band broadcasting is given primary allocation, although the frequency allocation table states:

> “**Radio Astronomy in the band 606-614 MHz is also to be protected from interference.**”

It is important that there exist allocations for radioastronomy throughout the licenced bands, since it is not possible to control the frequency which is used for transmission (unlike in the case of man-made signals). Given this, there are a number of other similar bands used for radioastronomy.

[139] PMSE-xG – see http://pmse-xg.research-project.de/index.html for details of the project
[140] PMSE-xG (2017): "PMSE and 5G", available at http://pmse-xg.research-project.de/publications.html
[141] Nokia and Sennheiser (2021) : « Low Latency 5G for Professional Audio Transmission", available at https://www.bell-labs.com/institute/white-papers/low-latency-5g-professional-audio-transmission/#gref

The penultimate of these bands is actually shared with PMSE, with a restriction on the power levels of the latter.

Given the existing equipment and investment in radio astronomy, along with the relatively small spectrum requirements in each band, it seems realistic for other spectrum users to work around these needs. However, it may be possible to limit the use of radio astronomy equipment to certain geographic regions, allowing for some use of this spectrum band by other users elsewhere.

4.3 PPDR

Public protection and disaster relief (PPDR) is a technology platform used by emergency services to communicate and share information during times of need. Many countries had established emergency services networks using narrowband technologies, but as information sharing became more important there have been a number of different proposals with how such needs should be met.

4.3.1 There are two types of PPDR network

Essentially, proposals for PPDR broadband can be categorised in two ways.

- A dedicated network, with its own defined spectrum. This has increased reliability and security, but will cost more (due to the need for entirely separate network infrastructure) and be an inefficient use of spectrum, with the majority of the band not being used except for times of crisis.

- A service provided by another network operator, with priority access for PPDR users. This is less costly and more efficient, but could be less reliable if the protocols identifying emergency users were not correctly specified; in addition, when PPDR users are given priority other users (such as members of the public who are trying to contact the emergency services) may suffer from a reduced service.

Given the low amount of spectrum available in the 700 MHz band, awarding a significant amount to PPDR will have an adverse impact on all other users. Further, the amount of spectrum assigned in France will not allow the emergency services to operate full LTE capabilities, let alone 5G technologies, over their networks, reducing the utility they may gain.

Indeed, in ECC Report 199 (published in May 2013), CEPT noted that the chosen technology for future European broadband PPDR systems should be LTE, with a standard spectrum requirement of 2×10 MHz. By 2016, the technology requirement was revised to LTE-Advanced, still requiring the larger spectrum band.

4.3.2 PPDR requires low-band spectrum

Given the nature of emergency service use, it is clear that low-band spectrum availability is important.

- Signals must be able to penetrate through walls and other obstacles, to enable rescue and search efforts.

- Temporary networks should be quick to set up with low power requirements.

- Devices should have long battery lives.

All of these factors would lead to difficulties with higher frequency spectrum. However, this must be balanced against the bandwidth available in lower frequency bands.

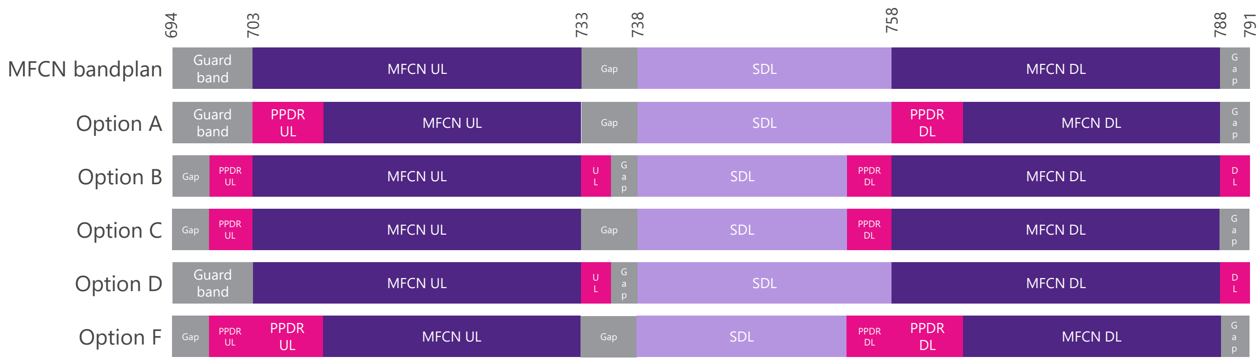
4.3.3 There is a limited agreement in Europe for PPDR in the 700 MHz band

Current narrow-band PPDR services use 380MHz – 400 MHz, which can become subject to re-farming as 2G-like systems as TETRA and Tetrapol reach their end of life. For broadband PPDR, different countries have taken different stances on this issue. CEPT has harmonised spectrum in the 410-430 MHz, the 450 MHz and the 700 MHz ranges. France has assigned two dedicated bands in 700 MHz for PPDR use (one 2×5 MHz band and one 2×3 MHz band), while the UK has instead awarded the PPDR contract to EE, the largest mobile network operator, with strict conditions on coverage and prioritisation.

The French example draws on a European-wide framework agreed in 2015. At that point there were a number of options identified in the 700 MHz band with how dedicated spectrum for PPDR, should it be required, would be included in the Europe-wide band plan. Members of CEPT were presented with a number of options:

- A dedicated 2×10 MHz block at the bottom of the standard mobile 700 MHz band plan, therefore reducing the amount available to mobile operators;
- Various options fitting the PPDR use into guard bands, allowing for different amounts of spectrum; or
- A combination of the two.

Figure 4.1: Options for PPDR spectrum in 700 MHz[142]



The recommendation of Option B in the diagram above led to 2×8 MHz of spectrum being made available, with some risk of interference from the supplementary downlink band in the centre of 700 MHz. This has retained most of the 700 MHz band for mobile use, with a reduction in the supplemental downlink capacity and reduced guard bands.

Outside of Europe, PPDR use is more varied; a number of countries use 800MHz bands for this service, while others reserve spectrum in the 2300MHz band. Although, as set out above, there are advantages to using UHF spectrum for PPDR, this is not necessarily reflective of the needs of every country.

4.3.4 Additional spectrum for mobile services in sub-700 MHz would benefit PPDR

As can be seen, where PPDR is being served using dedicated spectrum, these networks do not meet the proposed minimum requirements as defined in ECC Report 199. This will become even more problematic as the technologies available to PPDR users improve. It is likely that increasing use of remotely-controlled search robots, video coordination of police movements, and real-time routing for fire services, will lead to significant

[142] Source: adapted from http://www.emceurope.org/2016/workshops/WS8A_3.pdf

spectrum shortages. While some of this capacity could be carried on higher frequency bands, as noted above the use of UHF spectrum will remain crucial.

However, as noted above, the current availability of dedicated sub 1-GHz spectrum for PPDR is limited. The needs of PPDR reflect those of all mobile technologies, and where additional spectrum is available, PPDR can benefit from shared access to the enhanced performance of the MNO networks. This leads to a more efficient use of spectrum, but would require a public policy agreement on prioritisation. In addition, it is likely that in many countries the cost of deploying a separate high-quality network for PPDR will be prohibitive, meaning that more extensive coverage can only be obtained through implementing security and priority protocols on a public network.

Where dedicated spectrum has already been assigned, this could be achieved though a hybrid network, with critical communications using the PPDR-exclusive bands and support commnications using the public mobile networks. For example, in Germany the police use Tetra for critical voice communications, and use configured smartphones with specific applications on MNO networks for supporting data.

As a result, an increase in UHF allocation for mobile use would also benefit PPDR users.

5 A flexible approach to UHF allocation

Sections 2, 3 and 4 above have demonstrated the importance of UHF spectrum in a number of different services. Some of these services, such as mobile telecommunications and PPDR, are experiencing constantly increasing demand and further need for spectrum, while others continue to require UHF bands to operate. Against this overall demand for spectrum, however, we see a more nuanced regional picture, with some countries requiring significant retained spectrum for television broadcasting, while others already have much lower demands.

Given this regional variation, it is clear that a uniform policy on UHF spectrum use will not be optimum.

- If the band were reserved for mobile use only, countries where the majority of the population currently rely on terrestrial television broadcasting will need to undertake an extensive programme of alternative technology investment, whether through satellite, cable, or IP broadcasting, to ensure continuity of service. Customers would likely suffer from significant disruption, and the number of television channels may be adversely affected.

- If the band were retained solely for broadcasting use, then countries where television broadcasting is mainly or completely carried out over alternative technologies (or where only a small number of channels are broadcast) would be unable to make full use of the spectrum band. For example, where DTT services have been turned off in Belgium and Switzerland, those spectrum allocations are now sitting mostly empty.

Regional variations do not exist only in the broadcasting industry. The need for UHF spectrum on mobile networks depends on the demographics and geography of a country, with smaller, more dense city-states being able to rely more heavily on higher frequencies while countries with large rural areas more rely on low band coverage. The need for PMSE spectrum depends on the industries that use it; the need for radioastronomy depend on the scientific base.

Given this, it is crucial that the assignment of UHF spectrum is carried out at a more local level, rather than being set as a fixed assignment over the entirety of ITU Region 1. This is becoming more important as trends in broadcasting and mobile broadband use change, but with different timelines among regions and countries within regions.

5.1 Co-primary allocation is an important step

Currently, the band 470 MHz – 694 MHz is allocated on a primary basis to television broadcasting, with PMSE and radioastronomy afforded a secondary allocation (although the protection from interference for radio astronomy effectively gives it a primary allocation). Mobile services are allocated 703 MHz – 960 MHz (with significant set-asides for low-power devices and other telephone apparatus). There is no fixed allocation for PPDR, although CEPT recommendations assign 2×8 MHz in the 700 MHz band (mostly within existing guard bands), although this (as set out above) may not allow for efficient use of spectrum.

To allow for a flexible usage of UHF spectrum, depending on national circumstances, the 470 MHz – 694 MHz band should be assigned a co-primary status between television broadcasting and mobile telecommunications. The secondary use of PMSE and radioastronomy would remain, and national regulators would need to take the needs of these services into account when deciding on how the UHF band should be awarded. National decisions can consider local differences in demand, such as allowing PMSE in cities while mobile is allocated in rural areas. By setting broadcast and mobile services as co-primary, national regulators and governments would be able to consider how to make optimum efficient use of their spectrum, while still maintaining the benefits gained from international harmonisation. Additional harmonisation and convergence my arise from 5G broadcast addressing 470 MHz – 694 MHz as planned in 3GPP Release 17.

5.2 Interference between users will need to be taken into account

While it is clear that a co-primary allocation would increase the ability of national regulators to make decisions to improve the efficiency of use of spectrum – and therefore improve the welfare of uses – it would raise some significant issues over interference between services, particularly in border areas. This would be most pronounced along borders between countries with a current high demand for DTT (such as Italy) and countries which would prefer to use the majority of the spectrum for mobile services (such as Switzerland).

While some minor interference would be caused by handsets, the key issue is interference between DTT transmitters and mobile base stations. It is not possible to have co-channel DTT and IMT use overlapping without interference which would mean neither can be used without excessive exclusion areas around borders. In particular, DTT broadcast has a wide footprint and often crosses national borders due to historic mast placement.

It is, however, possible to mitigate a significant proportion of this interference. Neighbouring countries will generally already have bi-lateral agreements for coordination of television broadcast channels, and these will form a good starting point, allowing for mutually compatible television and mobile deployments. 3GPP carrier bandwidths like 8 MHz allow to efficiently fit into the existing broadcast plans. If such coordination is successful, the border areas sterilised may be relatively small in practice; DTT and LTE protection ratios are relatively relaxed when compared to the previous requirements for analogue television services.

In some cases, mitigation measures including pointing base station antennas away from borders or introducing downtilting can improve the sharing conditions. Sharing of available frequency channels between IMT and DTT near border areas and introducing guard bands can also improve the situation (although the latter may be a complex solution given the need for harmonisation to ensure an ecosystem). A number of other potential mitigation measures have been explored by CEPT in previous work[143]. Looking forward, if 5G is integrated within DTT networks, coordination will become easier.

Due to the relative size and power of transmissions, the main issue will remain DTT interference into mobile base station receivers. Base station placement, power, and direction can overcome some DTT interference without creating additional interference to DTT users, but a small number of macrocells will define the limits to this mitigation – those in exposed sites with little possibility of applying large values of downtilt.

With these mitigation techniques, requiring cooperation between countries, the adverse impacts of interference can be reduced, if not entirely eliminated. Even with only the mitigation measure of pointing antennae away from the border there are significant improvements:

> **“It was calculated that the separation distances were reduced to 14-20 km (for DVB-T/T2) and 33 km (for ATSC and ISDB-T) when it was assumed that the IMT base station antennas were pointing away from the DTT coverage area ”**[144]

[143] See, for example, CEPT Report 29 (2009): "Guideline on cross border coordination issues between mobile services in one country and broadcasting services in another country"
[144] From ITU-R Joint Task Group 4-5-6-7, Document 4-5-6-7/TEMP/136-E

5.3 A flexible spectrum allocation will enable significant benefits

As we have shown throughout this paper, there are a number of different ways in which UHF spectrum – focussing on the spectrum below 700 MHz but also considering spectrum above it – can be used to bring benefits to the population. Historic use of the spectrum for television has been an important step to providing people with access to free-to-air television services, and in some countries this spectrum remains a crucial part of the broadcasting infrastructure. However, in other regions the spectrum is either unused or is used inefficiently, and regulators and governments would be able to realise significant benefits if they were able to assign part of the band to mobile services, while still taking account of the needs of other users and cross-border interference. Where additional spectrum were released to mobile use, rural areas and transport routes would be able to access high-quality broadband networks like those found in cities.

To ensure that such a decision is made appropriately, it should be taken at the local level with sufficient diligence, rather than controlled on a global or near-global scale. This is only possible with co-primary allocation between mobile and broadcasting services.

Given that, this paper recommends that the spectrum should be allocated on a co-primary basis to broadcasting and mobile services at WRC-23, with national governments and regulators able to make decisions over the future use of UHF in an appropriate timeframe. In making decisions over how the spectrum should be awarded, the public bodies would need to:

- Consider the current and future use of DTT, and examine whether it would be possible to reduce the amount of spectrum used or have additional services running concurrently in the band;
- Develop regional and national roadmaps for the potential of introducing mobile services in the 470-694 MHz band which would be based on the respective market demands in different regions;
- Liaise with neighbouring countries to mitigate any interference caused by different services sharing channels across borders; and
- Examine the ways in which other users of UHF spectrum can be accommodated.

With careful planning of allocations, a more efficient use of spectrum could increase welfare considerably.

Appendix A Detailed studies on rural benefits

Figure 5.1: Studies on rural benefits of connectivity (voice[145] and data)

S.No.	Name of the research paper	Author names	Main Finding	Link
1.	Does the Internet Reduce Gender Gaps? The Case of Jordan	Viollaz and Winkler, 2020	Using panel data at the individual level with rich information on labor market outcomes, Internet use and gender-biased social norms, paper finds that the Internet adoption increases female labor force participation but has no effect on male labor force participation. It exploits the massive roll-out of mobile broadband technology in Jordan between 2010 and 2016.	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3554092
2.	Determinants of Mobile Broadband Use in Developing Economies: Evidence from Sub-Saharan Africa	Hasbi and Dubus, 2019	The study uses micro-level data coming from household surveys over 5 years, from 2013 to 2017. The paper finds a positive correlation between digital inclusion and financial inclusion as mobile money users and bank account users are found to be more inclined to use mobile broadband. The paper also finds that in Nigeria, mobile broadband is used to look for jobs by the unemployed and students use it for information gathering in other countries.	https://econpapers.repec.org/paper/halwpaper/hal-02264651.htm
3.	Can the Internet improve agricultural production? Evidence from Viet Nam	Kaila and Tarp, 2019	The paper estimates the relationship between Internet access and agricultural production in rural Viet Nam using a panel dataset from 2008–2012. Findings suggest that Internet access is associated with a 6.8% higher volume in total agricultural output.	https://onlinelibrary.wiley.com/doi/full/10.1111/agec.12517
4.	The Effect of Access to Information and Communication Technology on Household Labor Income: Evidence from One Laptop Per Child in Uruguay	Marandino, 2017	This paper examines the effect of the One Laptop Per Child program in Uruguay (Plan Ceibal) on household labour income. It finds that there is a statistically significant positive effect of the plan on household labour income for households below median income, specifically, those at the 10th and 20th quantiles.	https://www.researchgate.net/publication/319922379_The_Effect_of_Access_to_Information_and_Communication_Technology_on_Household_Labor_Income_Evidence_from_One_Laptop_Per_Child_in_Uruguay

[145] The table includes a couple of older papers that studied the effect of voice connectivity on the lives of the rural poor. We have included those in this table as that also suggests the impact of broader ICT infrastructure on the lives of the poor and

S.No.	Name of the research paper	Author names	Main Finding	Link
5.	Information Access and Smallholder Farmers' Selling Decisions in Peru	Salas-Garcia and Fan, 2015	The study finds that access to Internet positively affects Peruvian smallholder farmers' decisions to sell in both national and international markets and tends to have a larger impact on the decisions to sell in the national market. Results provide empirical support for policies and social programs that promote Internet usage and mobile phone coverage for rural Peru.	https://econpapers.repec.org/paper/agsaaea15/205380.htm
6.	Overcoming Obstacles: The Internet's Contribution to Firm Development	Paunov and Rollo, 2014	Based on 49,610 firm observations across 117 developing and emerging countries for 2006–2011. The paper finds that the adoption of Internet in different industries had positive spill over effects on firms' productivity across world regions and economies at different development stages.	https://academic.oup.com/wber/article/29/suppl_1/S192/1686970
7.	The effect of Internet and cell phones on employment and agricultural production in rural villages in Peru.	Ritter and Guerrero, 2014	The paper analyzed the impact of a program that subsidized Internet access in rural and remote areas of Peru. It found that the program increased employment of the educated, single, and young individuals. The program also led to an increase in the price farmers received for their traditional products and in the production of more processed goods.	https://pirhua.udep.edu.pe/bitstream/handle/11042/1902/ECO-L_001.pdf?isAllowed=y&sequence=1
8.	The Effects of Mobile Phone Infrastructure: Evidence from Rural Peru.	Beuermann et al, 2012	The main findings suggest that mobile phone expansion has increased household real consumption by 11 per cent, reduced poverty incidence by 8 percentage points and decreased extreme poverty by 5.4 percentage points.	https://www.researchgate.net/publication/254447443_The_Effects_of_Mobile_Phone_Infrastructure_Evidence_from_Rural_Peru
9.	Information, Direct Access to Farmers, and Rural Market Performance in Central India	Goyal, 2010	The paper estimates the impact of a change in procurement strategy of a private buyer in the central Indian state of Madhya Pradesh. The study found that the introduction of Internet kiosks led to an increase in soy price and cultivation.	https://www.researchgate.net/publication/40783722_Information_Direct_Access_to_Farmers_and_Rural_Market_Performance_in_Central_India
10.	Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries.	Aker 2011	The article outlines the potential mechanisms through which ICT could facilitate agricultural adoption and the provision of extension services in developing countries.	https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1574-0862.2011.00545.x

S.No.	Name of the research paper	Author names	Main Finding	Link
11.	Cell Phones and Rural Labor Markets: Evidence from South Africa	Klonner and Nolen 2010	The paper finds substantial effects of network roll-out on labor market outcomes with remarkable gender-specific differences. Employment increases by 15 percentage points when a locality receives network coverage. A gender-differentiated analysis shows that most of this effect is due to increased employment by women, in particular those who are not burdened with large childcare responsibilities at their homes. All the employment gains accrue in wage employed occupations. Agricultural employment decreases substantially, especially among males.	https://ideas.repec.org/p/zbw/gdec10/56.html

Appendix B DTT status in Region 1

The following figures provides statistics on the status of DTT standards and services across in ITU Region 1.

Figure B.1: DTT standards adopted in Region 1 countries[146]

DTT standard	All Region 1 (%)	ASMG (%)	ATU (%)	CEPT (%)
DVB-T2 only	48 (45%)	9 (53%)	22 (63%)	10 (24%)
DVB-T and T2	26 (25%)	5 (29%)	2 (6%)	17 (40%)
DVB-T only	19 (18%)	1 (6%)	1 (3%)	15 (36%)
ISDB-T	2 (2%)	-	1 (3%)	-
Unclear	11 (10%)	2 (12%)	9 (26%)	-
Total countries	106	17	35	42

Figure B.2: National free-to-air DTT services in Region 1 countries[147]

National services	All Region 1 (%)	ASMG (%)	ATU (%)	CEPT (%)
No national service	2 (3%)	1 (9%)	1 (5%)	0
1-10	38 (51%)	7 (64%)	10 (50%)	17 (46%)
11-20	21 (28%)	2 (18%)	6 (30%)	12 (32%)
21-30	7 (9%)	1 (9%)	1 (5%)	5 (14%)
>30	7 (9%)	0 (0%)	2 (10%)	3 (8%)
Total countries	75	11	19	37
Average	15.9	9.4	13.8	17.5
Median	10	6	10	11

[146] Source: Responses to ITU questionnaires (2013 and 2020).
[147] Source: Responses to ITU questionnaires (2020).

Figure B.3: Regional free-to-air DTT services in Region 1 countries[148]

Regional services	All Region 1 (%)	ASMG (%)	ATU (%)	CEPT (%)
No regional service	22 (29%)	5 (45%)	6 (32%)	9 (24%)
1-10	24 (32%)	5 (45%)	7 (37%)	11 (30%)
11-20	11 (15%)	0 (0%)	2 (11%)	6 (16%)
21-30	3 (4%)	1 (9%)	1 (5%)	1 (3%)
>30	15 (20%)	0 (0%)	3 (16%)	10 (27%)
Total countries	75	11	19	37
Average	31.3	4.5	12.8	51.3
Median	5	1	2	10

Figure B.4: Pay DTT services in Region 1 countries[149]

Pay services	All Region 1 (%)	ASMG (%)	ATU (%)	CEPT (%)
No pay service	36 (47%)	12 (100%)	5 (26%)	15 (41%)
1-10	6 (8%)	0	3 (16%)	2 (5%)
11-20	5 (7%)	0	1 (5%)	4 (11%)
21-30	3 (4%)	0	0	3 (8%)
31-50	9 (12%)	0	1 (5%)	6 (16%)
51-100	12 (16%)	0	4 (21%)	7 (19%)
>100	5 (7%)	0	5 (26%)	0
Total countries	76	12	19	37
Average	34.9	0	89.0	22.0
Median	2	0	50	16

Figure B.5: DTT multiplexes and services by country[150]

Region	Country	Muxes in 470-694 MHz		DTT services			UHF spectrum needs (MHz)
		National	Regional	National FTA	Local FTA	Pay	
CEPT	Albania	2	1	23	21	79	320
ASMG	Algeria	6	6	6	0	0	224
ATU	Angola	7	0	3	3	0	≥224 MHz and < 320 MHz
RCC	Armenia	4	4	8	17	0	224
CEPT	Austria	4	3	11	37	41	224

[148] Source: Responses to ITU questionnaires (2020).
[149] Source: Responses to ITU questionnaires (2020).
[150] Source: Responses to ITU questionnaires (2020).

Region	Country	Muxes in 470-694 MHz		DTT services			UHF spectrum needs (MHz)
		National	Regional	National FTA	Local FTA	Pay	
CEPT	Azerbaijan	3	9	11	10	0	224
ASMG	Bahrain	4	4	6	6	0	224
CEPT	Belarus	4	1	9	12	52	224
CEPT	Belgium (Flemish) Belgium (French) Belgium (German)	6 6 4	- 4 4	- 4 4	- 1 0	16 - -	224
-	Botswana	1	0	6	0	0	-
-	Cabo Verde	4	3	7	0	44	224
ATU	Côte d'Ivoire	4	4	7	1	50	228
CEPT	Croatia	6	1	11	20	60	244
CEPT	Cyprus	5	0	15	0	0	224
CEPT	Czech Republic	7	0	50	40	0	224
CEPT	Denmark	5	1	4	16	33	224
ASMG	Egypt	4	2	18	6	0	136
CEPT	Estonia	8	0	4	0	36	224
ATU	Eswatini	1	1	2	2	0	56
CEPT	Finland	6	3	21	9	38	>224
CEPT	France	6	1	27	43	5	224
CEPT	Germany	6	1	15	19	21	224
ATU	Ghana	25	1	60	20	600	224
CEPT	Greece	5	24	12	106	0	224
ATU	Guinea	4	4	0	2	96	224
ATU	Guinea-Bissau	4	0	1	0	0	224
CEPT	Hungary	5	2	12	32	64	224
CEPT	Iceland	2	3	2	2	20	224
CEPT	Ireland	6	0	11	0	0	224
CEPT	Italy	12	4	106	411	20	224
ASMG	Jordan	0	0	2	2	0	224
RCC	Kazakhstan	2	2	80	50	0	224
ATU	Kenya	10	3	34	73	127	224
ASMG	Kuwait	4	4	30	30	0	128
RCC	Kyrgyz Republic	5	5	48	15	0	320
CEPT	Latvia	4	1	5	1	57	224
ATU	Liberia	3	3	4	4	180	224
CEPT	Luxembourg	3	0	11	0	0	32

Region	Country	Muxes in 470-694 MHz		DTT services			UHF spectrum needs (MHz)
		National	Regional	National FTA	Local FTA	Pay	
ATU	Madagascar	4	4	10	0	54	-
ATU	Malawi	2	2	14	2	2	224
CEPT	Malta	13	0	8	0	58	104
ATU	Mauritius	28	7	18	0	0	224
CEPT	Moldova	2	1	15	0	0	224
CEPT	Montenegro	6	7	5	0	31	224
ASMG	Morocco	8	0	10	1	0	224
ATU	Mozambique	3	6	17	17	300	224
ATU	Namibia	4	4	5	0	2	224
CEPT	Netherlands	5	5	3	12	27	224
ATU	Nigeria	4	4	30	30	4	224
CEPT	North Macedonia	6	1	10	18	45	224
CEPT	Norway	5	5	3	10	30	224
ASMG	Oman	2	0	4	0	0	224
ASMG	Palestine	6	4	10	0	0	112
CEPT	Portugal	5	1	7	2	0	224
ASMG	Qatar	2	0	4	0	0	224
CEPT	Romania	4	2	9	1	0	224
CEPT	Russian Federation	2	2	20	150	0	376
ASMG	Saudi Arabia	0	0	-	-	0	-
ATU	Senegal	4	4	19	0	60	224
CEPT	Slovak Republic	4	0	8	0	12	224
CEPT	Slovenia	2	1	6	6	6	30
ATU	South Africa	7	7	8	6	15	224
-	South Sudan	12	3	3	20	1	-
CEPT	Spain	7	4	26	750	0	239
ASMG	Sudan (Republic of)	10	2	-	-	-	224
CEPT	Sweden	6	6	6	4	61	224
CEPT	Switzerland	0	2	5	1	0	-
RCC	Tajikistan	12	4	8	10	61	-
ATU	Tanzania	4	4	13	34	101	224
ASMG	Tunisia	4	4	13	0	0	224
CEPT	Turkey	4	1	-	-	-	224
CEPT	Ukraine	5	3	28	130	0	28

Region	Country	Muxes in 470-694 MHz		DTT services			UHF spectrum needs (MHz)
		National	Regional	National FTA	Local FTA	Pay	
ASMG	United Arab Emirates	2	2	0	5	0	144
CEPT	United Kingdom	6	2	113	34	0	224
RCC	Uzbekistan	4	8	19	40	45	224
CEPT	Vatican City State	4	0	13	0	0	224
ATU	Zambia	2	6	5	50	99	224
ATU	Zimbabwe	4	4	12	0	0	224