ZetaCast

Technical Evolution of the DTT Platform

An independent report by ZetaCast, commissioned by Ofcom

Principal Authors:	Ken McCann, Adriana Mattei
Contributing Authors:	Jeff Gledhill, Guy Hirson

Version:	1.3
Date:	28 January 2012

CONTENTS

1 Executive Summary and Conclusions

This report provides a review of possible scenarios for the technical evolution of the Digital Terrestrial Television platform. The main findings are as follows:

Video Formats

1. In order to continue to provide a competitive and attractive proposition for consumers, the DTT platform should be capable of providing services based on the 1080p 50Hz video format from about 2015
   - Production technology is rapidly migrating to 1080p
   - An increasingly high percentage of the TVs sold in the UK are now 1080p capable
2. UHDTV (4Kx2K) displays should start to become available at consumer prices from about 2015. The initial price is likely to be relatively high, but then reduce over time following a similar pattern to that of the corresponding 1080p display technologies
   - UHDTV displays will be used to view non-broadcast content and to provide a means of showing an unconverted version of broadcast HDTV content, especially 1080p
   - UHDTV production is still at an experimental stage and is unlikely to become mainstream for at least a decade
3. Stereoscopic 3D services are assumed to form a relatively minor part of the total service offering and hence will not have a significant effect on the overall DTT bitrate requirement
   - e.g. 2 full resolution 3D programming channels would require approximately the same bitrate as 3 normal channels

Video and Audio Compression

4. The emerging HEVC video compression standard appears to be on track to provide a factor of 2 improvement in coding efficiency over H.264/AVC
   - The same quality at half the bit-rate of H.264/AVC
   - Similar to the improvement that H.264/AVC offers over MPEG-2
   - Standardisation work is due to complete in January 2013
5. Considerable momentum has built up around the HEVC development process so it reasonable to assume that products based on HEVC will be available by 2014 or 2015
   - All of the major TV manufacturers and silicon vendors have large teams actively participating in the HEVC standard development
6. It is unlikely that there will be major changes in the bit-rate required to be set aside for the audio component of broadcast programmes in the immediate future
   - Improvements in audio compression efficiency will be offset by increases in the number of surround sound channels

Terrestrial Channel Coding and Modulation

7. It is probable that DVB-T2 will continue to be the channel coding and modulation method that is used for some time
   - DVB-T2 is close to the theoretical limits for near line-of-sight reception

- Adding MIMO techniques could potentially almost double the capacity, but this would require costly new transmission and home antenna installations

Evolution of DTT Platform

8. It is probable that the current pattern of both industry and consumers supporting a new generation of DTT technology roughly every 10 years will continue, at least until the 3rd Generation.
   - Since each generation tends to remain active for about 20 years, some form of triple-casting is likely to remain necessary for some time
     - Currently: analogue TV, SDTV (1st Generation DTT), HDTV (2nd Generation DTT)
9. 3rd Generation DTT services, giving both better video quality and more efficient use of capacity, should be viable from about 2015 based on:
   - DVB-T2 channel coding and modulation
   - HEVC video compression
   - 1080p as primary video format
     - 720p could be useful as a secondary video format, in order to increase the total number of available services
     - It should be possible to provide a larger number of 720p services in a 3rd Generation mux than SDTV services in a 1st Generation mux
10. The pattern of a new generation of DTT technology every 10 years would imply a possible 4th Generation DTT in around 2025
    - However, there is currently no clear indication of any specific new compression and/or modulation technologies that this may contain
    - It is possible that Moore's Law, the main driver for improvements in compression efficiency, may cease to be valid by 2025
    - This report does not explicitly consider the introduction of a 4th Generation DTT

Alternative TV Platforms

11. Wired broadband IP networks can be expected to retain about an order of magnitude advantage in download bit-rate relative to wireless networks, as both sets of technologies continue to evolve
    - Wireless networks are convenient for mobile devices and may also play an important role in providing broadband access in rural areas
12. The IPTV platform in the UK is still constrained by limitations to the forward path bandwidth
    - This weakness can be expected to disappear when newer network technologies are deployed, as has already happened in France
13. The main strengths of the satellite broadcasting platform are the high bandwidth of the forward path and the relatively low cost of operating a broadcast network that covers virtually all UK households
    - It is probable that 1080p services will start to become available on satellite by 2015

14. The main strength of the cable platform is the integration of broadband IP connectivity
    - It is probable that 1080p services will start to become available on cable shortly after they become available on the satellite platform

Spectrum Issues

15. The total amount of spectrum available for DTT may change over time
    - Extra spectrum may become available for DTT services after digital switch-over
    - Spectrum re-planning at a later date may result in DTT spectrum being re-assigned to other services, such as mobile broadband

Scenarios for DTT Platform Development

16. The speed at which the transition between different generations of technology occurs is a key issue, with contradictory drivers
    - A rapid launch and expansion of 3rd Generation DTT services would maximise spectral efficiency and ensure the long-term competiveness of the DTT platform, but would restrict the number of SDTV and HDTV channels that could be carried in the medium term
        - The effective timing of launch of 3rd Generation services could be influenced by the association with distinctive service propositions intended to drive and benefit from technology take-up
    - A rapid expansion of 2nd Generation HDTV services would make the DTT platform more competitive in the medium term, but would endanger its long-term future by inhibiting the transition to 3rd Generation services
    - A slow phasing out of 1st Generation technology would maximise short-term stability and protect the existing investment in consumer equipment, but would reduce the overall competiveness of DTT relative to alternative platforms in both the medium and long term
17. A total of twelve possible scenarios for the evolution of the DTT platform were considered
    - Different combinations of transition timing and spectral usage
    - Many further scenarios could be envisaged
18. The scenarios included four alternatives in the timing of technology transitions:
    - Roll-out of 3rd Generation services in 2015, 1st Generation services switched off in 2025
    - Roll-out of 3rd Generation services in 2015, 1st Generation services switched off in 2030
    - Roll-out of 3rd Generation services in 2020, 1st Generation services switched off in 2030
    - No Roll-out of 3rd Generation services, 1st Generation services switched off in 2030
19. Three possibilities for spectral usage were considered:
    - DTT reducing to 3 multiplexes from 2025
    - DTT remaining at 6 multiplexes throughout the period under consideration
    - DTT increasing to 9 multiplexes in 2015, reverting to 6 multiplexes in 2025

Governance Issues

20. The ability to make a timely transition between the various generations of DTT technologies is likely to be dependent on the extent to which the governance structure supports coordinated action by stakeholders

2 Video formats for display and production

2.1 Increasing Video Resolution

2.1.1 HDTV and 1080p

A useful metric for comparing different video formats is the number of picture elements (pixels) per second, typically expressed in Mpixel/s. The current High Definition TV (HDTV) [18] transmissions generally use one of the following two formats:

- "720p", i.e. 1280 pixels x 720 lines at 50 frames/s (progressive) – 46 Mpixel/s
- "1080i", i.e. 1920 pixels x 1080 lines at 25 frames/s (interlaced) – 52 Mpixel/s

There has been a vigorous debate on the relative merits of the two formats over the years, with advocates of 720p pointing to its better motion portrayal and more efficient compression, whilst proponents of 1080i highlight its superior static resolution.

The 1080i format is often broadcast at a reduced horizontal resolution of 1440 pixels x 1080 lines, corresponding to 39 Mpixel/s. The bit-rate required for this reduced resolution version of 1080i is fairly similar to that required for 720p; the pixel rate is lower than that of 720p, but the lower pixel rate is offset by the reduction in compression efficiency due to the use of interlace.

From the point of view of a content provider, the existence of the two HDTV formats is an unwanted complication. The best way to be able to provide content for transmission in either format is to produce it in a third format:

- "1080p", i.e. 1920 pixels x 1080 lines at 50 frames/s (progressive) – 104 Mpixel/s

1080p provides good quality down-sampling to either 720p or else 1080i, hence maintaining the value of a content provider's archive. The current revision of the DVB Video and Audio Coding Specification [7] also allows the direct transmission of 1080p video to provide an improved quality HDTV service, but this has not yet been adopted by any broadcaster.

Recent top-of-the-range screens will display 1080p, but the limitations of the decoder act as major a barrier to using 1080p for transmission. A 1080p decoder requires double the memory bandwidth of 1080i, which was a significant technical problem when the current HDTV standards were devised. Although no great technical challenge today, this has created a legacy problem with most of the currently deployed set-top-boxes.

2.1.2 Ultra High Definition TV (UHDTV)

In this report, resolutions higher that 1080p will be generically referred to as Ultra High Definition TV (UHDTV). A number of other names are used elsewhere: Super Hi-Vision (SHV), Ultra High Definition Video (UHDV), Extreme Definition Video, etc.

Two main classifications are envisaged, representing 4 times and 16 times the resolution of 1080p respectively:

- "4Kx2K", e.g. 3840 pixels x 2160 lines – 415 Mpixel/s
- "8Kx4K", e.g. 7680 pixels x 4320 lines – 1659 Mpixel/s

There are also some variants of these formats, so that "4Kx2K" may also be used to refer to 4096 pixels x 2048 lines, 4096 pixels x 2304 lines or 4112 pixels x 2168 lines.

The 4Kx2K format was first proposed in the Digital Cinema Initiative, since it offers a resolution comparable to that of 35mm film. The 8Kx4K format was first proposed by NHK in Japan for the “Super Hi-Vision” system; it gives similar resolution to IMAX film. It is not envisaged that any of the UHDTV formats will be interlaced.

2.1.3 Perceptual Limit to Resolution

The generally accepted rule of thumb for the smallest object that a person with normal vision can discern is about 1 minute of arc. This was confirmed by a test performed by the BBC in 2004 which measured an average value of 1.054 for 18 observers. The implication is that the pixel structure of a 1080p system would remain invisible unless the screen occupied an angle of more than about 18° vertically, corresponding to just over 30° horizontally for a 16:9 screen.

The results for a range of video resolutions are summarised in the Table 1 below; these all assume a flat screen and hence the relationship between display resolution and viewing angle is not linear.

	Approximate Horizontal viewing angle for 1 pixel per arc minute
720p: 1280 pixels x 720 lines	20°
1080p: 1920 pixels x 1080 lines	30°
4Kx2K: 3840 pixels x 2160 lines	55°
8Kx4K: 7680 pixels x 4320 lines	100°

Table 1: Maximum Horizontal Viewing Angle

A BBC study of domestic viewing arrangements [19] found that UK viewers sat at an average of about 2.7m from the screen. From this distance, the pixel structure of a 1080p system would be assumed to be invisible unless the diagonal screen size was greater than about 65 inches, if 1 pixel per arc minute is used as the threshold.

2.2 Other Display Enhancements

2.2.1 Stereoscopic and 3D Display Techniques

The human vision system has no direct means of analysing the three-dimensional nature of a scene; the third dimension is inferred from various cues delivered through our binocular vision system. The most important of these cues is parallax, the difference between the views seen by the left and right eye, which is greater for the closer objects.

A stereoscopic effect can be obtained from video on a flat two-dimensional (2D) screen by employing some form of filtering to ensure that information representing a different perspective is presented to each eye. The filtering process may rely on glasses (filtering by polarisation or temporal shutters) or may be inherent in the display itself (an auto-stereoscopic display). Such plano-stereoscopic displays are often referred to as “3D”, but this is not strictly correct; in a true three dimensional display the scene observed would be dependent on the position of the viewer and occluded objects would become visible if the viewer moved.

Each of the possible 3D display technologies has its own distinct advantages and disadvantages, which are summarised in Table 2 below.

	Advantages	Disadvantages
Stereoscopic TV using Polarised glasses	Good quality "3D" Good quality 2D Low cost passive glasses	Requires new LCD display with micro-polarisation Display cost increased due to micro-polarisation Reduced spatial resolution when viewing "3D"
Stereoscopic TV using Shutter glasses	Good quality "3D" Good quality 2D Does not increase cost of display	Requires display with high refresh rate Reduced temporal resolution when viewing "3D" Relatively expensive active glasses
Auto-stereoscopic TV	No glasses	Requires expensive new display Currently offers a mediocre "3D" experience with limited viewing angles Lenticular lens degrades viewing of 2D content
Head mounted stereoscopic display	Full quality "3D" without any filtering Immersive viewing experience	Requires expensive individual display for each viewer Not suitable for social viewing
Light Field, Holographic or Volumetric displays	True 3D (not just stereoscopic)	Unlikely to be available at consumer prices in the foreseeable future

Table 2: Stereoscopic and 3D Display Technologies

A fuller discussion of possible 3D technology is included in a previous ZetaCast study, entitled "Beyond HDTV: Implications for Digital Delivery" [22].

2.2.2 Increasing Frame Rate

The 50Hz field rate (i.e. 25Hz frame rate) used for analogue TV in Europe was originally chosen because of its convenient linkage with the frequency used for mains electrical power, rather than for any consideration of psycho-visual optimisation. Although mains frequency is no longer an important issue with digital TV technology, the historical frame rates have been maintained, so that the world is now divided into areas that use the 50Hz family and those that use the 60Hz family of frame rates.

When moving from interlaced SDTV to progressive HDTV formats such as 720p or 1080p, the frame rates are doubled from 25Hz to 50Hz by the removal of interlace. This provides more realistic motion portrayal, which is particularly noticeable with sports material.

When introducing UHDTV, it would be possible to consider doubling the frame rates again, to 100Hz. Many top of the range HDTV sets today already use internal frame doubling to 100Hz or beyond. This technique works satisfactorily to reduce the visibility of flicker in static areas, but operating the entire broadcast chain at 100Hz would extend this benefit to further improving the motion portrayal. Alternatively, UHDTV could be used as an opportunity to launch a new family of frame rates. For example, a 75Hz, 150Hz and 300Hz family of frame rates could provide a path to convergence between the traditional 50Hz and 60Hz families.

2.2.3 Increasing Aspect Ratio

The old 4:3 format for analogue TVs was replaced by the 16:9 "widescreen" format with the move to digital SDTV and HDTV. This is closer to the aspect ratio used in the cinema, but a mismatch remains; 16:9 corresponds to an aspect ratio 1.78, whilst most movie titles use an ultra widescreen aspect ratio of 2.33 or 2.39. The HDTV viewer looking at movies filmed in an ultra widescreen format such as CinemaScope therefore has to accept either black bars at the top and bottom of the screen or else cropping of the right and left of the picture.

In principle, there is no reason why there could not be a future transition of domestic displays from 16:9 to an ultra widescreen. Philips has recently launched a series of 21:9 TVs that display 2.39 aspect ratio movie material in high definition (2560×1080), with the aim giving a true anamorphic cinematic viewing experience in the home. When such a display is used with normal HDTV content it has to either stretch the 16:9 video to fill in the screen or else add black bars on the sides. It remains to be seen how much consumer interest there is in this type of product.

2.2.4 Increasing Chrominance Resolution

Established broadcasting practice is to transmit video which represents chrominance information with half the resolution, in both the horizontal and vertical direction, of that of the luminance information. For historical reasons, this format is designated as 4:2:0 (where the first number represents the sampling frequency of the luminance, whilst the second and third numbers represent the sampling frequency of the chrominance on odd and even lines respectively).

Video content is generally originally shot with the same vertical chrominance resolution as that of luminance, but with half the horizontal resolution, designated as 4:2:2. Film content is generally shot with the same chrominance and luminance resolution, designated as 4:4:4.

In principle, a future broadcasting standard could increase the relative resolution of the chrominance information to 4:2:2 or even 4:4:4. However, the disparity between the luminance and chrominance resolution represented by current practice appears to be well-matched to the characteristics of the human eye. This study will assume that 4:2:0 continues to be used for broadcasting applications.

2.2.5 Increasing Bit depth

The video information in digital broadcasting transmissions is currently represented with 8 bit accuracy, although 10 or 12 bit representation is generally used in digital production. The quantisation due to 8 bit representation becomes most visible when there is a gradual but consistent variation of colour, e.g. in an area of clear sky at sunset.

The quantisation effects are likely to become more apparent as video resolution is increased. The introduction of 1080p or UHDTV broadcasts could therefore be combined with an improvement of the bit depth, probably using some form of adaptive coding. This would be unlikely to require any significant increase in bit-rate, since contouring due to quantisation is generally most visible on relatively easy to encode video content.

2.2.6 Improving Colour space

The colour space for HDTV systems has been based on ITU-R Recommendation BT.709 [16] since its adoption in 1990. Rec. 709 represented a major step forward in replacing the range of different colour gamuts previously in use with various SDTV systems worldwide, and was subsequently also endorsed by the computer industry as "sRGB". However, it was still designed around the limitations of the phosphors in CRT-based display technologies and hence it does not allow all real-world colours to be reproduced.

Many modern consumer display devices are already capable of displaying a wider colour gamut than is permitted by Rec.709. In 2006, IEC adopted the "xvYCC" colour gamut [17], which is backwards-compatible with ITU-R Rec. 709 but which allows a wider range of colours to be reproduced. There are some areas of colour-space where the differences are quite noticeable, e.g. shades of deep rose-red. This standard is supported by the major consumer display manufacturers and it is expected that there will be increasing momentum behind its wider adoption. This is not expected to require any noticeable increase in bit-rate.

2.3 Market Trends in Displays and Production

2.3.1 Display Resolution and Broadcast Resolution

Historically, display resolutions and frame rates have tended to match that of the broadcast video signal. This no longer appears to be the case, particularly following the advent of 1080p displays. Consumers are now frequently buying displays with a resolution and frame rate that surpasses that of any source that they have available. They still see improved picture quality due to the good performance of modern consumer grade up-convertors.

This trend is expected to continue in the future, when 4Kx2K displays will appear in the market before any 4Kx2K signals are broadcast. The up-conversion to 4Kx2K is likely to be most effective with 1080p content rather than any lower resolution.

2.3.2 Display Market Trends

2.3.2.1 1080p Displays

All major TV manufacturers are selling 1080p displays and their cost has fallen significantly in the past few years. At the time of writing, 42" 1080p displays were available for under £400 and even displays as large as 60" were available for under £1000. In dixons.co.uk, the number of 1080p ("full HD") models available for sale considerably exceeded the number of 720p models.

A study by Quixel Research indicated that 51% of LCD TVs shipped in 2010 worldwide were 1080p, showing an increase in market share of 8% since 2009.

2.3.2.2 Stereoscopic ("3D") Displays

Most major TV manufactures have now launched stereoscopic displays on the market. The cost of these displays has come down considerably and they are now being sold with virtually no incremental cost over the non-3D models, at least for stereoscopic TVs using shutter glasses.

According to dixons.co.uk, 40% of the TV models available for sale support 3D. Dixons has stated that 3DTV sales have increased by 500% over the past twelve months. This very significant increase in sales has been attributed by Dixons to lower prices, greater availability of 3D content and the fact that 3D capability is increasingly found on a wider range of flat-screen TVs. More than 80% of the 3DTV sets available to buy in Dixons are 1080p.

Futuresource Consulting predicts that within 3 years nearly half of all UK households will own a 3DTV set. It suggests that most consumers will end up owning a 3D set by default, sometimes unaware of the fact at the time of purchase.

2.3.2.3 4Kx2K Displays

Prototype 4Kx2K displays have been demonstrated since around 2006. Several of the major display manufactures have made some move towards introducing such UHDTV products on the market, using both plasma and LCD technologies. For example, Toshiba's P56QHD 56" 4Kx2K LCD display is commercially available for about £25,000.

The current price of the few UHDTV displays that are commercially available is well above the level required for consumer acceptance. However, it is reasonable to assume that these prices will reduce dramatically over the next few years, following a similar pattern to the corresponding HDTV and 3DTV display technologies over the past decade. It is therefore likely that 4Kx2K displays will start to become available at consumer prices from about 2015.

2.3.3 Production Market Trends

2.3.3.1 1080p Production

For a content provider wishing to maintain the long-term value of their output, it makes sense to move to 1080p production as soon as practical. This has some value even in the short term, since 1080p provides good quality down-sampling to either 720p or else 1080i transmission.

ESPN announced that it had the world's first 1080p60 production centre in 2009. This move has subsequently been followed by many other broadcasters in both the 50Hz and 60Hz worlds. BBC Studios and Post Production (S&PP) stated in 2010 that it had upgraded Studio Six at Television Centre in White City to what is thought to be the UK's first 1080p50-capable studio.

2.3.3.2 Stereoscopic ("3D") Production

A fuller discussion of 3D content is included in a previous ZetaCast report in July 2009, entitled "Beyond HDTV: Implications for Digital Delivery" [22]. The first page of the executive summary included a graph showing the Gartner Hype Cycle [42] (see Figure 1 below) together with the statement that "*the current situation for stereoscopic TV displays has all of the characteristics of a classic 'Peak of Inflated Expectations'*".

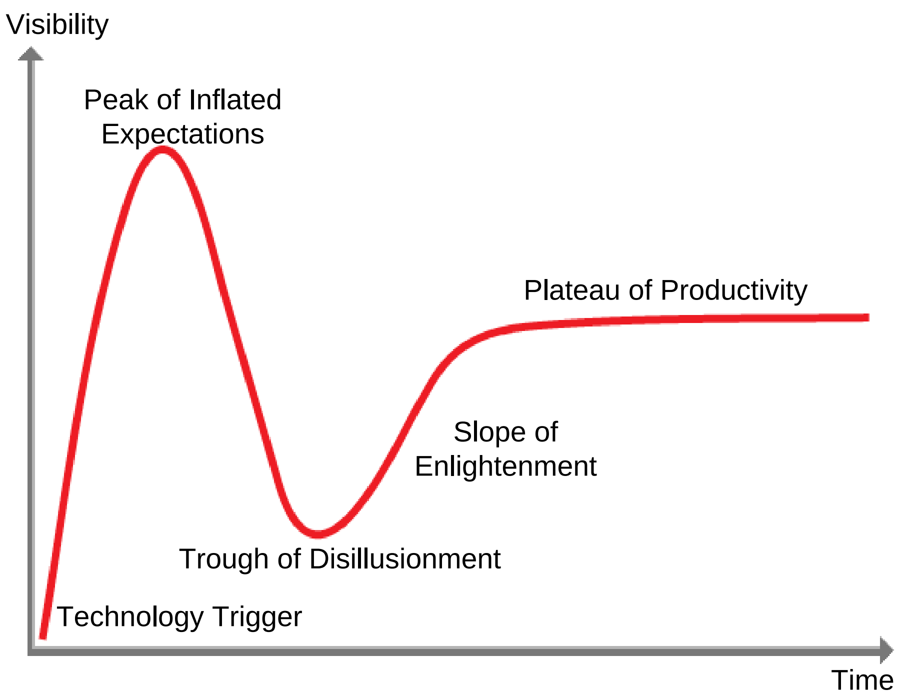


Figure 1: Garter Hype Cycle

Events since 2009 imply that the introduction of stereoscopic TV continues to follow the stages of the Gartner Hype Cycle, but with the situation at the time of writing this report representing the early stages of the plunge towards the 'Trough of Disillusionment'. For example, the French pay TV operator Canal Plus has recently announced that it will close its 3D channel on 24 January 2012.

The 2009 ZetaCast report said that it was not clear what the real long-term consumer demand for stereoscopic TV in the home would be and suggested that the 'Plateau of Productivity' would be reached by 2020.

This report will assume that 3D is likely to exist as a relatively minor part of the overall platform offering, for example as one or two dedicated 3D terrestrial channels.

2.3.3.3 UHDTV Production (4Kx2K and 8Kx4K)

Production at UHDTV resolution is still at the experimental stage, both for 4Kx2K and 8Kx4K. For example, the BBC has announced that it will trial Super High Definition (8Kx4K) during the London 2012 Olympics, together with NHK.

This study will assume that 4Kx2K production and broadcasting will not be of major importance for at least a decade.

3 Video and Audio Compression

3.1 Current Video Coding Standards

3.1.1 MPEG-2 and H.264/AVC

The current generation of video compression technology, H.264/AVC [5], provides approximately a factor of two improvement in compression efficiency compared to the previous generation, MPEG-2 [2]. This ability to get the same quality of video at half the bitrate has provided an important technology enabler for the launch of HDTV services, particularly via terrestrial transmission.

MPEG-2 and H.264/AVC follow same basic architecture, a hybrid motion compensated block transform. However, they differ in the details of the component parts of that architecture: motion compensation, block transform, variable length coding, etc.

Both standards were developed jointly by ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG). MPEG-2 video was published in 1995 as ISO/IEC 13818-2 and ITU-T Recommendation H.262 [2]. H.264/AVC was published in 2003 as technically aligned twin text in ITU-T Recommendation H.264 and ISO/IEC 14496-10 [5]. In both cases, the video compression standards were added to the DVB audio-visual coding standard, TS 101 154 [7], about one year after completion by MPEG and VCEG.

3.1.2 Using H.264/AVC for Stereoscopic 3DTV

There are two main approaches that have been used to add stereoscopic 3D functionality within the H.264/AVC standard.

The first approach is to use frame-compatible (FC) coding, where the decoded HD video frame contains two distinct views that have been spatially packed together. One of these views is seen by the viewer's left eye whilst the other is seen by the viewer's right eye, by using suitable displays with polarised or shutter glasses. This approach has the advantage of allowing extensive re-use of both the existing broadcasting infrastructure and existing decoding devices. There are two main disadvantages: it delivers only half resolution video to each eye and the required broadcast bit-rate is relatively high, approximately 200% of the bit-rate that would be required to deliver a 2D signal of half resolution. Within DVB, this approach has been referred to as "Phase 1" and the corresponding mechanism has been added to TS 101 154. This approach is used in the majority of current 3D broadcasts, including BSkyB's 3D channel.

The second approach requires new decoders, but gives a more efficient method of coding stereoscopic 3D by using one of the Multiview Video Coding (MVC) profiles within the H.264/AVC standard. The most appropriate choice for broadcasters would probably be the Stereo High Profile, which has already been adopted for stereoscopic Blu-ray discs. The view intended for one eye is coded conventionally as the base view; this view can be decoded by a 2D H.264/AVC decoder to give 2D service compatibility. The view for the other eye is encoded as a difference signal relative to the base view, thus giving more efficient compression. The required total bitrate is typically in the range 140 - 180% of that required to deliver a 2D signal of the same resolution, depending on the nature of the content (e.g. interlaced content tends to be less efficiently encoded than progressive). This approach has been referred to as "Phase 2a" within

DVB and the technical work to determine how to include this option in TS 101 154 is currently underway.

In addition to the two methods described above, various alternative approaches to adding stereoscopic 3D functionality within the H.264/AVC standard are also under consideration by the standardisation bodies. These include:

- FC-compatible coding. The base view is a FC signal which can deliver half resolution 3D to an existing "Phase 1" decoder. A difference signal provides the additional information relative to the base view to allow a new decoder to produce full resolution video for each eye. The total bit-rate required would be slightly greater than that for MVC for the same subjective quality.
- Tile format. This is a type of frame-compatible approach where two 720p views are packed together in a 1080p frame. 1080p capable decoders are required and the bit-rate is approximately 200% of that would be needed to deliver a 2D signal of 720p resolution.
- MVC compatible extension. MPEG began work in November 2011 on an extension to H.264/AVC to add efficient coding of depth information to MVC. This would support enhanced user control of the 3D viewing experience in applications such as Blu-ray, but is likely to be of limited relevance in broadcasting applications due to the difficulty of producing real-time depth maps. The target is for this extension to be published from a Final Draft Amendment in October 2011.
- AVC compatible extension. MPEG also began work in November 2011 on a slightly longer term extension to H.264/AVC that would be an alternative to MVC. The goal of this extension is to both provide 3D enhancements and also improve the coding efficiency relative to MVC. The target is for this extension to be published from a Final Draft Amendment in January 2012.

3.2 Emerging Video Coding Standards

3.2.1 High Efficiency Video Coding (HEVC)

A new video compression standard, known as High Efficiency Video Coding (HEVC), is currently being developed jointly by ISO/IEC MPEG and ITU-T VCEG. The overall goal is once again to achieve approximately a factor of two improvement in compression efficiency compared to the previous generation (H.264/AVC). A wide range of video resolutions will be covered, from low resolution right up to the UHD resolutions of 4Kx2K and 8Kx4K.

The first step towards creating HEVC was the launch of a joint Call for Proposals in January 2010. A total of 27 proposals were received; a fairly impressive response, given the amount of work that was required to prepare a proposal. Each proposal was tested using 18 video sequences, 5 bitrates and 2 constraint sets. The 18 sequences covered five classes of video resolution, ranging from quarter WVGA up to 4Kx2K. The 5 bitrates were chosen to provide a range of video qualities from highly stressed to good quality encoding. For example, the 1080p 50 and 60 Hz sequences were tested at bitrates ranging from 2 to 10 Mbit/s. Given the target of a factor of two increase in coding efficiency, this roughly corresponded to the quality of a current H.264/AVC encoder operating at 4 to 20 Mbit/s. Two constraint sets were defined for the encoding: the first typical of broadcasting applications with limits to the time for a channel change, the second typical of conversational services, with limited encode/decode delay.

Two different types of quality measurements were performed, both using a standard software implementation of H.264/AVC as a lower anchor. Firstly, objective measurements were made using the Peak Signal-to-Noise Ratio (PSNR), i.e. the ratio between the energy in the encode/decode error and the energy in the original picture. PSNR is a commonly used and convenient method of giving an approximate indication of the likely video quality. However, despite many years of trying to come up with an accurate objective measurement, the only way to really determine video quality remains the rather awkward and expensive process of running subjective tests with real people.

An extensive programme of formal subjective testing was therefore performed. A total of around 23,000 video clips were tested; this appears to be the largest subjective quality testing effort ever carried out in the history of video compression. The test was organised in 134 sessions of approximately 20 minutes each, using a total of 850 test subjects over a one month period. This was really too much for any single laboratory to cope with, so the burden of testing was shared between three sites: FUB in Rome, EBU in Geneva and EPFL in Lausanne.

The technical details and results of the HEVC Call for Proposals were analysed during the first meeting of the Joint Collaborative Team on Video Coding (JCT-VC) in April 2010. The basic architecture for all of the proposed algorithms was once again a hybrid motion-compensated block transform. Within this traditional architecture many innovative new tools were proposed, with larger block sizes and a more flexible block structure being common themes.

The test results were very encouraging, especially at 1080p resolution and above. A consistent trend was that the reduction in bit-rate relative to the anchors was greater when considering equal subjective quality than when considering equal PSNR. JCT-VC decided not to adopt a "winner takes all" approach and instead defined a "Test Model under Consideration", which combined specific elements from seven of the leading proposals.

The first formal HEVC test model, "HM1", was defined in October 2010. This was largely a selection of the better-performing tools from the "Test Model under Consideration", following a detailed analysis of their individual contributions. Further optimizations of the HEVC Test Model in HM2, HM3, HM4 and HM5 were specified at subsequent meetings, with each successive model achieving better performance than the previous in terms of the trade-off between coding efficiency and complexity.

At the time of writing this report, no formal subjective tests have yet been published using the HEVC Test Models. However, a paper providing test results based on PSNR has recently been submitted for publication at the IEEE International Symposium on Circuits and Systems (ISCAS), 20–23 May 2012 [23]. When compared to a H.264/AVC anchor configuration, the HM4 design was reported to provide bit rate savings for equal PSNR of about 44% for the 1080p sequences in the "random access" configuration. Assuming that the HM shows the same trend of greater bit-rate saving for equal subjective quality than for equal PSNR quality that was consistently observed in the Call for Proposals, the HEVC development appears to be on target to deliver a factor of two improvement in compression efficiency compared to H.264/AVC.

The HEVC standard is scheduled to reach Committee Draft stage in February 2012 and to be published from Final Draft International Standard in January 2013. A considerable momentum is building up around the development process, with a total of 284 participants at the seventh JCT-VC meeting, held in Geneva in November 2011. All of the major TV manufacturers and silicon vendors have teams actively participating in this work, so it is reasonable to assume that their product plans are already in an advanced stage of development.

3.2.2 Using HEVC for Stereoscopic 3DTV

The addition of 3D coding to HEVC is planned to be left to a subsequent extension. MPEG issued a Call for Proposals on 3D video (3DV) coding in March 2011, covering solutions based both on H.264/AVC and HEVC. The Call resulted in 22 responses which were analysed at the November 2011 MPEG meeting, half based on H.264/AVC and half based on HEVC technologies). In the case of HEVC, the target is both to enable efficient stereoscopic/multiview video coding and also to include depth support. It is expected that stereoscopic 3D coding using HEVC will require about 140-170% of the bitrate of 2D HEVC. The planned timescale is to reach Proposed Draft Amendment status in January 2013 and to be published from Final Draft Amendment in January 2014.

This study will assume that the required bitrate for stereoscopic 3D coding using HEVC will be about 150% of that of a normal 2D HEVC channel. This implies that the total bitrate required for two 3D services is the same as that required for three normal services.

3.3 Video Bitrates in Practice

3.3.1 Video Bitrate Changes over Time

There is a general trend of improving video coding efficiency over time. These improvements come in two forms. Firstly, there is a gradual evolution of encoders giving greater efficiency within a specification, where existing decoders can continue to be used. Secondly, there are occasional moments when there is a revolution caused by a change of algorithm, which requires new decoders.

The experience of MPEG-2 and H.264/AVC implies that consumers and the industry are prepared to consider such a revolutionary change of algorithm roughly once a decade, provided that it can be justified by about a factor of two improvement in coding efficiency. If this experience is extrapolated to HEVC, then the timetable shown in Table 3 below can be expected.

	Standard Published	Added to DVB	First Broadcast Services Launched
MPEG-2	1995	1996	1997
H.264/AVC	2003	2004	2005
HEVC	2013	2014	2015

Table 3: Historical and Probable Future Timetable for Video Coding Standards

The primary driver for both the periods of evolution and the moments of revolution is Moore's Law; more complex processing becomes practical over time. In an attempt to translate the effects of Moore's Law into bit-rate, the author presented the modestly named McCann's Law at DVB World in 2003. This originally stated that the bit-rate required to achieve a given video quality halves every five years, assuming that both evolutionary and revolutionary improvements are implemented as early as possible. It has subsequently been revised to predict that the bit-rate required to achieve a given video quality halves every 7 years.

In the real world, improvements do not follow a smooth curve as legacy issues prevent overly frequent changes of algorithm. This is illustrated in the graph in Figure 2 below, which shows the launch of broadcasts based on MPEG-2, H.264/AVC, HEVC and a possible future standard in 2025.

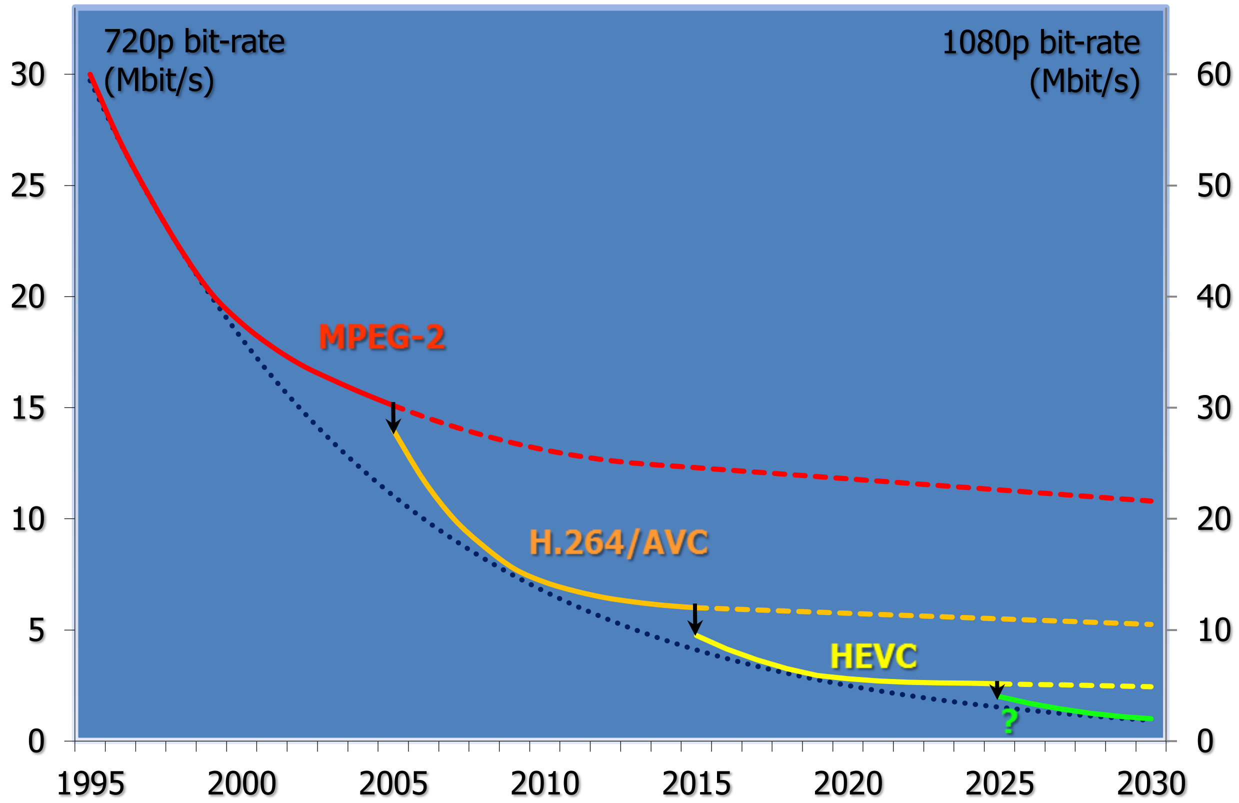


Figure 2: Illustration of Bitrate Trends in Practice

The left-hand vertical axis of the graph represents the typical bit-rate required for 720p format video in a particular year, the right-hand axis that for 1080p.

As explained in section 2.1.1, the pixel rate for 1080p is 2.25 times that of 720p. The bit-rate required to represent a video signal is roughly proportional to the pixel rate, but the relationship is slightly less than linear due to the tendency for higher resolution video to have greater correlation between adjacent pixels, hence allowing more efficient encoding. With current camera technology, 1080p video also tends to be slightly softer than 720p, further reducing the bit-rate increment currently required to represent the 1080p content. However, this latter effect is expected to disappear over time as 1080p camera technology matures. In Figure 2 it is assumed that the bit-rate required for 1080p is constantly 2 times that of 720p, although the multiplier is probably still less than 2 with today's 1080p camera technology.

3.3.2 Statistical Multiplexing

In a constant bit-rate system, each video service in the multiplex has a fixed allocation of data rate regardless of the nature of the video content. When statistical multiplexing is used, a lower data rate is allocated when the video is easy to encode, such as a head and shoulders shot of a news presenter sitting in a studio. A higher data rate is allocated when the video becomes more difficult, such as a sports clip within the news programme.

The improvement in coding efficiency due to sharing multiplex capacity increases with the number of programme channels, as the peaks and troughs of bit-rate demand across the channels average each other out better. The exact efficiency gain is also dependent on the choice of compression algorithm, the nature of the video content across the channels, the details of the implementation, etc.

To a first approximation, the other factors can be neglected and bit-rate savings can be expected to asymptotically approach a value of about 30% as the number of channels increases. The graph in Figure 3 below is indicative of the typical benefits that can be expected.

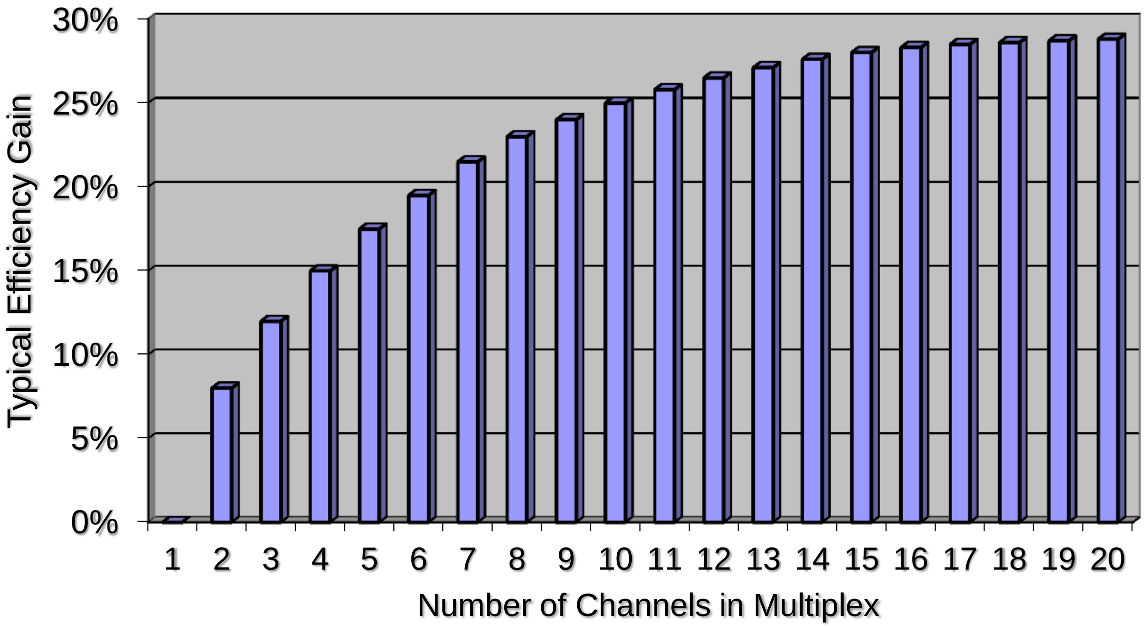


Figure 3: Typical Efficiency Gains through Statistical Multiplexing

3.4 Audio Compression Coding

Although some HDTV programming is still broadcast with only stereo sound, surround sound is an increasingly important part of much HDTV content. Currently, this is usually broadcast as 5.1 channels, i.e. 5 full range audio channels plus one low frequency effects channel. Home theatre systems are moving towards supporting 7.1 channels, which provide a slightly more immersive sound field, so it is possible that broadcasts will also move towards 7.1 in the future.

As with video, there is a general trend of progressive improvements in audio compression efficiency, so that the bitrate required to achieve a given audio quality decreases with time. However, the advances in audio coding efficiency tend to occur more slowly than with video. Furthermore, many of the recent developments in audio coding have focussed on improving the coding efficiency at quality points lower than would generally be used for broadcasting.

For current broadcasting applications, the most important family of MPEG audio codecs is Advanced Audio Coding (AAC), which was originally developed as part of the MPEG-2 audio standard [3]. The MPEG-4 audio standard [4] includes a set of technologies designed to address a broad range of audio coding requirements, from extremely low bit-rate parametric coding up to near-lossless quality at higher bit-rates. The most relevant for broadcasting are the Advanced

Audio Coding Low Complexity (AAC-LC) audio object and the High Efficiency AAC (HE-AAC) profile, which adds Spectral Band Replication to AAC-LC.

Proprietary audio codecs are also important in broadcasting applications, particularly Dolby Digital (AC-3) and Dolby Digital Plus (Enhanced AC-3), which have been published via ETSI [6]. A major strength of the Dolby family of solutions is the comprehensive metadata: the descriptive data that accompanies the audio content.

The European Broadcasting Union (EBU) Project Group on Multichannel Audio Evaluations performed an extensive subjective assessment of the sound quality of 5.1 channel audio coders for broadcast applications in 2007 [19]. The EBU tested about 20 different codecs using more than 110 assessors from 8 laboratories. Of the codec and bit-rate combinations tested, an average of "excellent" quality was found to be given by:

- Dolby Digital at 448 kbit/s
- AAC at 320 kbit/s
- HE-AAC at 160 kbit/s or192 kbit/s

These results imply that, if compression efficiency were the dominant criterion for selecting audio coding, then HE-AAC would be the obvious audio codec of choice at the moment. However audio content represents only a small proportion of the total bitrate required for an HDTV programme, so other decision criteria such as the ability to integrate the metadata conveniently within the broadcaster's workflow may be more significant.

There are no immediate plans in MPEG to develop even more efficient audio coding solutions for encoding 5.1 channel or 7.1 channel content at broadcast quality. Instead, the emphasis for the next phase of work will be on adding functionality for "3D Audio". This is intended to provide a highly immersive audio experience in which the decoding device renders a 3D audio scene including a vertical component to the audio image, e.g. using 22.2 channel configurations.

This report will assume that there will be no major changes in the bit-rate required to be set aside for the audio component of broadcast programmes in the immediate future; improvements in audio compression efficiency will be offset by increases in the number of surround sound channels.

4 Terrestrial Channel Coding and Modulation

4.1 Introduction to the DVB Family of Terrestrial Channel Coding

4.1.1 DVB-T

DVB-T [12] was developed in the mid to late 1990s, building on work conducted in a number of European research laboratories in the preceding decade. Like the earlier Digital Audio Broadcasting (DAB) system it uses a multicarrier modulation scheme known as Coded Orthogonal Frequency Division Multiplexing (COFDM). This gives excellent immunity to multipath reception, as well as resistance to interference from analogue television transmission systems.

Two variants of the system were defined, using either about 2000 or about 8000 carriers (2K or 8K). The former system gives better performance for mobile reception; the latter allows rejection of very long echoes which occur in a Single Frequency Network (SFN), i.e. a network of multiple transmitters working on the same frequency.

DVB-T uses the same error correction scheme as DVB-S [10]. This meant that the first generation receivers were able to use the same silicon as the already developed satellite receivers; an important advantage given that DVB-T equipment was required a very short time after the specification was finalised. Fortuitously, these codes give good performance when combined with the multicarrier modulation system.

On each carrier, modulation constellations up to 64QAM are allowed. This means that the system can transmit significantly more data per unit bandwidth than DVB-S, but at the expense of requiring greater signal strength at the receiver. DVB-T has a number of overheads which reduce data capacity, but aid performance and synchronisation in the receiver. These are the guard interval, and assorted 'pilots'. The amount of capacity allocated to pilots is significantly higher than the minimum that is theoretically required, partly because it simplifies the design of receivers.

A weakness of DVB-T is poor immunity to impulse interference. This could have been overcome by adding time interleaving, but at the time when the specification was developed it was not practical to add enough memory to give effective time interleaving in a consumer-priced receiver.

First generation chip sets for DVB-T reception in the UK were restricted to operating in the 2K carrier modes. This was also because it was not quite possible at the time to economically integrate enough memory to allow operation in the 8K modes. Because of Moore's law this soon ceased to be a problem, but the existence of these first generation chips did prevent a change to the use of 8K carriers until recently.

The DVB-T parameter set currently in use in the UK on the PSB multiplexes gives a capacity of about 24.1 Mbit/s:

- 64QAM modulation
- 1/32 Guard Interval
- 2/3 FEC Rate
- 8K FFT

The DVB-T parameter set to be used on the commercial multiplexes in the UK after digital switchover gives a capacity of about 27.1 Mbit/s:

- 64QAM modulation
- 1/32 Guard Interval
- 3/4 FEC Rate
- 8K FFT

4.1.2 DVB-T2

DVB-T2 [13] is the second generation terrestrial broadcasting system. Like DVB-T, it uses COFDM, but with up to 32K carriers. Using more carriers permits a shorter percentage guard interval, and hence a reduced loss of data capacity, for the same length of echoes as with DVB-T. It also has a lower overhead for pilots, closer to the theoretical minimum required to fully exploit a given guard interval.

DVB-T2 allows constellations of up to 256QAM per carrier, thus allowing a greater bitrate capacity in each 8MHz UHF channel. DVB-T2 follows DVB-T in inheriting its error correction scheme from the corresponding satellite system, in this case DVB-S2 [11]. The low-density parity-check (LDPC) codes are well-suited to use in applications that approximate to an additive white Gaussian noise (AWGN) channel, such as line-of-sight satellite reception. However, they are not as well-suited to terrestrial reception, where COFDM modulation is working in a channel with strong multipath reception. To partially overcome this, DVB-T2 defines 'rotated constellations'. These trade a small loss in AWGN performance for a significant gain in multipath performance.

The following parameters are currently being used for the UK's single DVB-T2 mux:

- 256QAM modulation
- 1/128 Guard Interval
- 2/3 LDPC FEC Rate
- 32K FFT

This combination gives a capacity of about 40.2 Mbit/s.

4.2 The transition from DVB-T to DVB-T2

Receiver chip sets for DVB-T2 became available shortly after the finalisation of the standard in 2008. Set top boxes for the reception of DVB-T2 and HDTV are readily available in UK shops, including models priced under £50 at the time of writing. Some DVB-T only televisions are still being sold, but sets including DVB-T2 tuners are becoming increasingly prevalent. Availability of suitable receiving equipment is therefore not a barrier to the expansion of DVB-T2 services. However, because of the large installed base of DVB-T receivers, it is not yet practical to immediately switch off DVB-T transmissions.

The situation in many other countries that have deployed DVB-T transmission is similar to the UK. For example, Italy has recently introduced a single DVB-T2 multiplex carrying both HDTV and SDTV services; most multiplexes are still DVB-T, carrying SDTV services and also a few HDTV services. Sweden is in the process of introducing two DVB-T2 multiplexes for HDTV.

Some countries that made a late start to DTT are now in the fortunate position of being able to begin with DVB-T2 transmission. Examples include some countries in Eastern Europe (e.g. Ukraine) and several in Africa (e.g. South Africa).

4.3 Extensions to DVB-T2 services

4.3.1 Alamouti Coding and Future Extension Frames

DVB-T2 transmissions to date have primarily been used to deliver higher bit rates than DVB-T, in deployments that are very similar to that of existing DVB-T transmissions. However, DVB-T2 also has the potential to be used with mobile and portable receivers, such as tablets or smart phones.

DVB-T2 specifies a form of dual antenna transmission diversity known as Alamouti coding. This gives protection against strong multipath, including "flat fading": the complete loss of signal caused by the cancellation of directly received signals with those reflected from a nearby object. The main disadvantage of this technique is the cost at the transmitter site, since it requires two transmitters and two antennas. The antennas should ideally be spaced as far apart as possible, but a spacing as low as ½ wavelength (about 30cm at low UHF frequencies) will still give significant gain. This technique could be very relevant if services for mobile reception are to be implemented in the future.

Another DVB-T2 technique which may be used is Future Extension Frames (FEF). These allow the DVB-T2 signal to be time-multiplexed with other services, including services that have yet to be defined. The first example of the use of FEFs is in DVB-T2 Lite (see section 4.3.2 below).

4.3.2 DVB-T2 Lite

DVB- T2-Lite is the first additional transmission frame type making use of the FEF approach (see section 4.3.1 above). It is a profile of DVB-T2 that was introduced in July 2011 to support mobile and portable TV, whilst also allowing for cost-reduced implementation. The new profile is defined as a subset that adds two additional LDPC code rates to the main DVB-T2 specification. The implementation complexity has been reduced, since only elements relevant for mobile and portable reception have been included in the DVB T2-Lite subset and the data rate has been restricted to 4 Mbit/s per Physical Layer Pipe (PLP).

DVB-T2 Lite uses FEFs to multiplex two DVB-T2 services together; the FEF mechanism allows T2-Lite and T2-base to be transmitted in a single UHF channel. Typically, one of the services is a high bitrate transmission for HDTV, which occupies most of the available time. A proportion of its available transmission time is 'stolen' by the second DVB-T2 service, which is typically configured in a very robust low bitrate mode for mobile reception.

Since DVB-T2 Lite is a relatively minor extension to the DVB-T2 standard, there would be no great technological barrier to implementing it in the near future. Whether or not there is a viable business case is another question.

4.3.3 DVB-T2 Legacy issues

It may seem strange to be considering DVB-T2 legacy issues when the technology has only recently been introduced, but as with DVB-T the capabilities and limitations of the first generation equipment will have consequences for years to come.

The first generation DVB-T2 chip sets have been targeted at a particular market; the introduction of high data rate HDTV services. These early chip sets may not necessarily have been tested in other modes and hence may not achieve the full theoretical performance of the specification. The DVB-T2 specification has so many parameters that it is would be extremely time-consuming to test a chip set in all possible modes.

Some specific features, such as Alamouti Coding and FEFs may also not be implemented in the early chips. In both these cases the DVB-T2 specification expresses an expectation that they should be implemented, but does not go so far as making them mandatory.

4.4 Future Terrestrial Broadcasting Specifications - DVB-T3?

4.4.1 DVB-T2 Evolution

When used for line-of-sight or near line-of-sight reception, DVB-T2 can be shown to perform at close to the theoretical limits. Even a radical change to coding and modulation could only achieve a small performance improvement, which is unlikely to be economically viable.

The theoretical limits to performance in severely fading channels is not as well understood, and there is some reason to believe that the combination of error correcting code and modulation used by DVB-T2 is not quite optimum for such channels. However, even if it were possible to achieve a performance improvement of several dB (which would be extremely difficult), the case for developing a whole new standard looks very doubtful, at least for the next decade or so.

4.4.2 MIMO

To get really significant improvements in performance, it is necessary to look at radical changes to both the transmission specification and infrastructure. One set of techniques, known as MIMO (multiple input multiple output) have only been partly exploited by the existing DVB-T2 standard. These techniques require the use of two or more antennas (and associated signal processing) at the transmitter, the receiver or both.

A particularly interesting implementation of a dual antenna MIMO system is where one antenna uses vertical whilst the other uses horizontal polarisation, at both transmitter and receiver. Signal processing would be needed at the receiver to separate the two transmissions, since they inevitably become partially mixed together. This MIMO technique is very powerful and could potentially give a near doubling of data capacity. The problem is that it requires both significant changes to the transmission infrastructure and new home aerial installations, for example a pair of cross-polar antennas.

A further possible extension of MIMO would involve an even more radical change to the transmission network, where the existing network would be replaced by a dense network of low power transmitters (like a cellular phone network but with even more base stations). For this to be effective, a typical receiver would have to be able to see several base stations simultaneously. The use of MIMO with many antennas at both transmitter and receiver would then theoretically allow total service bit rates several times higher than is currently achieved.

If there ever is a DVB-T3 standard, it could well be based on a modified DVB-T2 standard with more extensive use of MIMO techniques. However, the cost of making such radical changes to the broadcasting infrastructure would be considerable; it would also be difficult to persuade the consumer to invest in a corresponding new home antenna installation.

This report will assume that DVB-T2 will continue to be used for channel coding and modulation throughout the period under consideration.

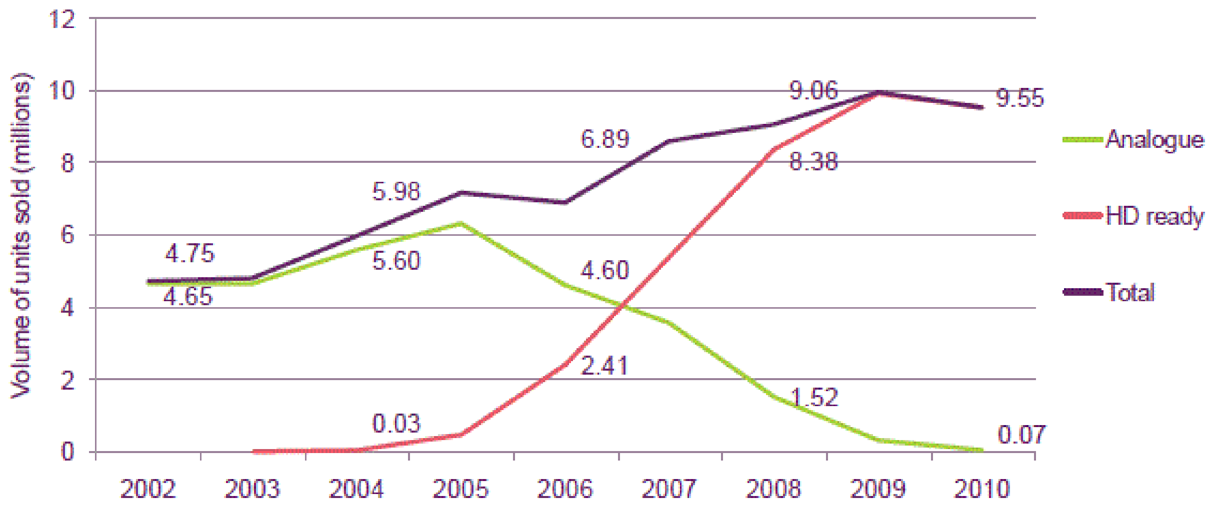
5 Evolution of DTT platform

5.1 Timescale Trends in TV Technology

5.1.1 Replacement Cycle for TV Receiving Equipment

Analogue TV technology was fairly static after the introduction of colour, so the incentive to upgrade a TV set or a STB before it was broken tended to be relatively low. The Global TV Replacement Study from DisplaySearch [38] mentions an average of between 10 and 15 years for the typical CRT to CRT replacement cycle in the past.

By contrast, the rapid pace of innovation enabled by digital TV technologies and services has resulted in a significantly shorter replacement cycle. The 2011 Ofcom Market Report [39] shows that the annual volume of TV set sales in the UK has approximately doubled in the past decade, from 4.75 million units in 2002 to 9.55 million units in 2010; see Figure 4 below.



Source: GFK sales data

Figure 4: Annual UK television set sales (2002 – 2010)

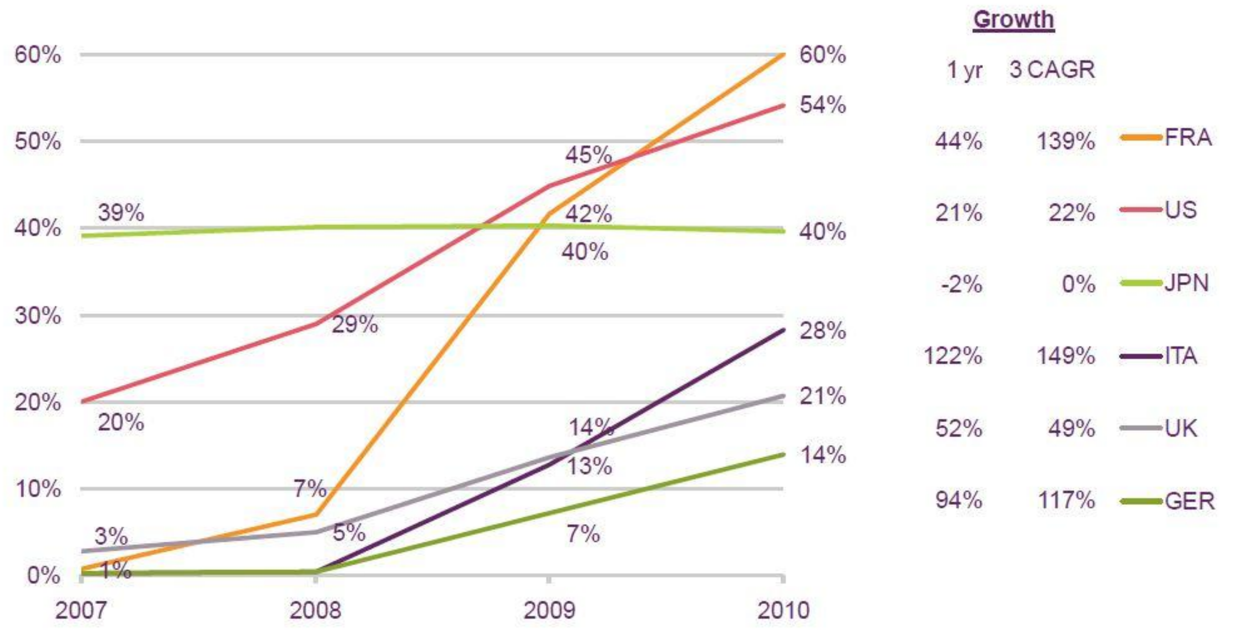
The introduction of digital TV services and the availability of affordable flat panel TVs gave consumers an initial motivation to upgrade from CRTs. The trend of relatively rapid replacement continued with the introduction of HDTV and various other enhancements. In addition, the pace of evolution of devices such as personal computers (e.g. netbooks), mobile phones (e.g. smartphones), music players (e.g. iPod) and tablets (e.g. iPad) has probably helped to generally set expectations for a faster rate of replacement for audio-visual devices.

According to the Value Partners' report for the BBC Trust in 2009 [40], the typical replacement cycles for primary digital receiving equipment are as follows:

- 7 - 8 years for integrated TVs
- 5 - 6 years for STBs

The more recent Ofcom Market Report [39] shows that the actual TV sales figures for 2010 were higher than had been predicted by Value Partners (9.55 million as opposed to 8.77 million), so the actual replacement cycle appears to be shorter than suggested above.

Ofcom's International Communications Market Report 2011 [41] reports that penetration of HDTV in the UK increased by a third in 2010, to reach the main television sets in 21% of households. It shows (see Figure 5 below) that the penetration of HDTV in France and the USA had passed the half-way point in 2010: 60% of households in France and 54% in the USA.



Source: IDATE / industry data / Ofcom.

Figure 5: Number of HDTV Homes by Country, end 2010

Other technologies that have become available more recently are also beginning to gather momentum among consumers. 13% of consumers in France have access to an internet-connected television, compared to 7% in the UK and the USA. 10% of viewers in Italy claim their main television set is 3D-ready, alongside 8% of those in Germany, 7% in France and 6% in the UK and Australia.

As there appears to be no sign of any slow-down in the flow of innovative ideas for future digital TV technology and services, it is probable that the trend for rapid replacement of consumer equipment will also continue for the foreseeable future.

5.1.2 Generations of TV Broadcasting Technology

Historical data gives a useful insight into the time between the launch of successive generations of digital TV broadcasting technology. In the case of satellite, 7½ years elapsed between the Sky Digital launch in October 1998 and the Sky HD launch in May 2006. In the case of terrestrial, the Freeview HD launch in March 2010 was 11½ years after the ONdigital launch in November 1998 (7½ years after the Freeview launch in October 2002). From these examples, the typical time between launching incompatible generations of digital TV broadcasts appears to be approximately 10 years.

The graph in Figure 6 below shows the equivalent process of successive generations of digital TV technology from the consumer point of view, by plotting the take-up of technology used in the main TV set in the home against time. The bars show the percentage of households where the main TV set was analogue, digital SDTV and digital HDTV, using data extracted from the 2011

Ofcom Market Report [39]. A "whole market" approach was taken, i.e. the total numbers include satellite, cable and terrestrial platforms, because there are cross-platform effects to the take up of technology in the market in general. It should be noted that the number of households where the main TV was digital SDTV peaked in 2008, since households with HDTV are excluded from the figures of those with SDTV.

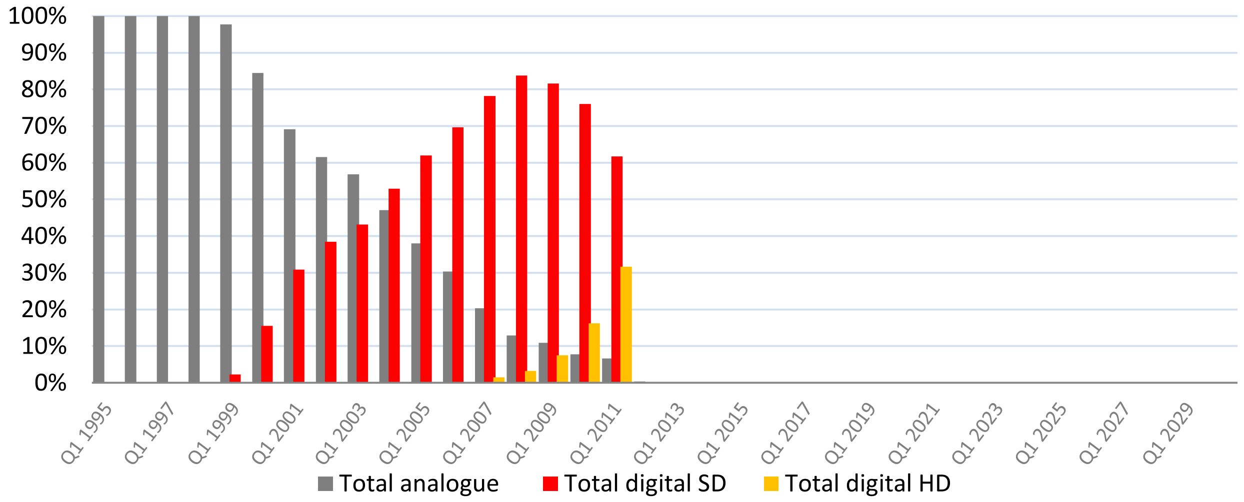


Figure 6: Technology Used in Main TV Set

Figure 7 below shows a DTT HDTV penetration forecast using data disclosed by 3 Reasons Ltd, a research house that regularly produces forecasts on the evolution of the UK TV landscape. The data was kindly made available for the purpose of inclusion in this report. It relates to the DTT platform only, without including other platforms. It shows a period of roughly 10 years for HDTV (over DTT) to reach over 90% coverage on primary sets.

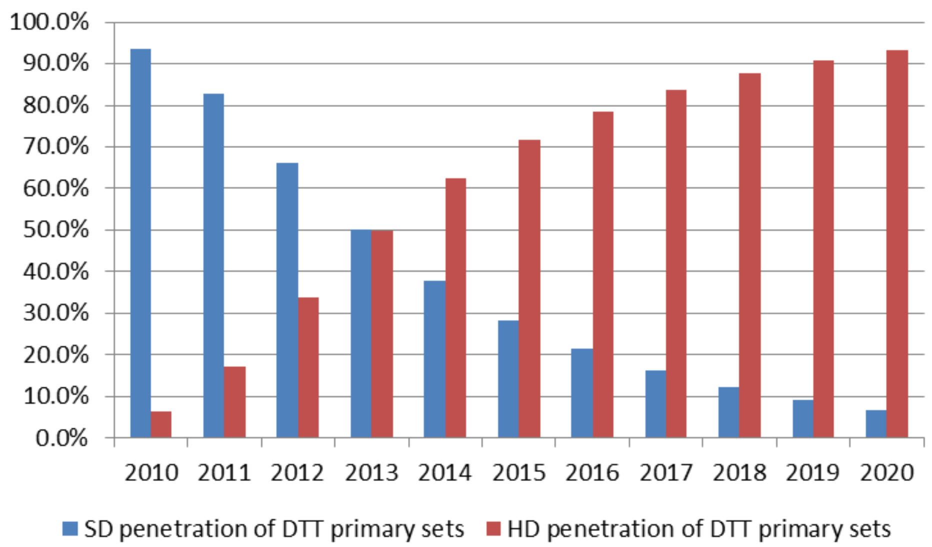


Figure 7: HDTV Household Penetration on the DTT Platform
(Data courtesy of "3 Reasons Ltd", Autumn 2011)

From consideration of the emerging High Efficiency Video Coding (HEVC) standard (see section 3.2), it looks probable that the pattern of a new generation of digital TV technology being launched roughly every 10 years will continue, at least until the 3rd Generation. This is illustrated in Figure 8 below, where the bars represent historical data and the line graphs show a possible extrapolation from the technology trends that have been observed to date.

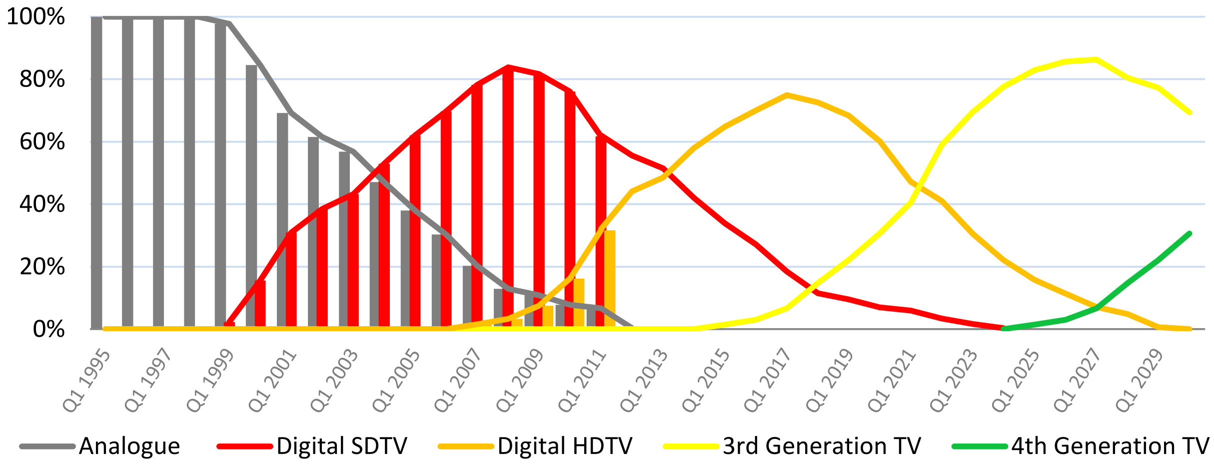


Figure 8: Possible Extrapolation of Technology Trends

Since each generation of digital technology tends to remain active for about 20 years, some form of triple-casting is likely to be a near-permanent feature if the DTT platform is to remain competitive with major technological developments. The current triple-casting is:

- Analogue TV
- SDTV (1st Generation DTT)
- HDTV (2nd Generation DTT)

5.2 Generations of TV Technology

The most probable package of 3rd Generation technologies to allow the DTT Platform to remain competitive is as follows:

- **Support for 1080p video format**
  The improved video quality of 1080p over 720p/1080i will give early adopters an incentive to upgrade their receivers and also allow DTT to remain competitive with the likely developments on alternative platforms. 720p could provide a useful secondary format for broadcasters, expected to be used by some channels with fewer viewers. 2Kx4K broadcasting is unlikely to be mainstream for at least a decade.

- **HEVC video compression**
  The emerging HEVC standard is appears to be on track to give approximately a factor of two improvement in coding efficiency compared to H.264/AVC, i.e. the same quality at half the bit-rate. H.264/AVC and MPEG-2 legacy support would still be required in the receiver. No successor to HEVC is expected for at least a decade.

- **DVB-T2 channel coding and modulation**
  There is no sign of any successor to the DVB-T2 appearing in the foreseeable future. Using DVB-T2 channel coding and modulation allows 2nd and 3rd Generation services to share a multiplex.

Previous terrestrial technology generations have been associated with new distinctive consumer propositions. 1st Generation DTT was associated with the launch of new multi-channel propositions (ITV Digital in 1998 and Freeview in 2002). More recently, the uptake 2nd Generation DTT has been sustained by the launch of Freeview HD. Similarly, it is possible that 3rd Generation technologies will be associated with new consumer propositions and that these will have to be sufficiently distinctive to drive the adoption of new technology. The timing and launch of such a new proposition will inevitably depend on the wider commercial and strategic incentives of the broadcasters. This, in turn, could have a significant impact on the timing and pace of adoption of 3rd Generation technologies.

The ongoing evolution of TV technology from one generation to the next is summarised in Figure 9 below, starting from analogue TV ("Generation 0") and proceeding to a possible 4th Generation of DTT, which would be unlikely to appear until the mid 2020s at the earliest.

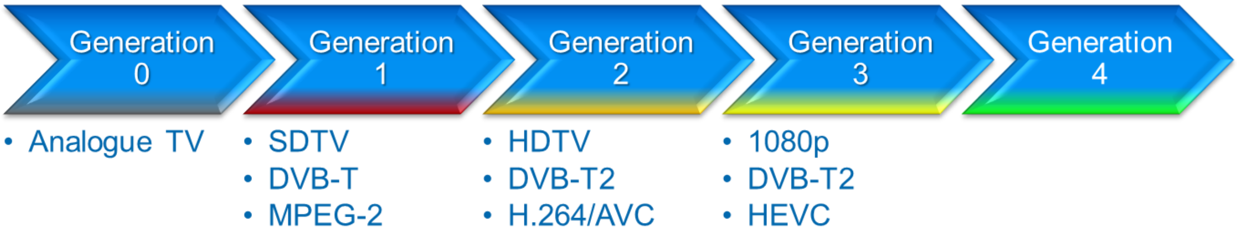


Figure 9: Generations of Terrestrial TV Technology

The use of set top boxes (STBs) was an important mechanism to allow consumers to extend the lifetime of their existing TV displays during the transitions from Generation 0 to 1 and from Generation 1 to 2. Once a particular generation of technology became established, it tended to be increasingly common for the appropriate STB functionality to be included in integrated TVs. It can be expected that a similar process will occur again with the transition from Generation 2 to Generation 3.

6 Alternative TV Platforms

6.1 Broadband IP Networks

6.1.1 Overview

Broadband Internet Protocol (IP) connectivity can be provided using a range of wired and wireless technologies. The different technologies have differing performance characteristics and are affected by different operational and environmental conditions. The actual bit-rate that the consumer receives is generally rather less than the headline "maximum bit-rate" figure quoted by the network operator. The actual bit-rate received depends on a number of factors:

- Distance from the consumer's end device to the network operators termination equipment.
- Number of users sharing the same capacity, sometimes called the contention ratio. This is predominantly determined by the design characteristics of the network, e.g. "cell size" or "homes passed per node".
- Economics of deploying a given technology per cell or node. In general, the cost tends to be higher for smaller cells, so operators frequently deploy cells just ahead of the demand curve.

6.1.2 Wired

6.1.2.1 Digital Subscriber Line (DSL)

Telecommunications networks, based on twisted pairs of copper wire, were originally designed and installed to carry voice frequencies over distances of several km from the local telephone exchange to the home. They can be used to provide broadband data services, via a modem in the customer premises and a Digital Subscriber Line Access Multiplexer in the exchange. The xDSL technologies use higher frequencies than voice services, so the signals attenuate more rapidly with distance from the exchange.

Most households in the UK can already use ADSL [24] modems to achieve a basic broadband experience, i.e. at least 2Mbit/s. However, this is insufficient for broadcast-quality video streaming. ADSL2 [25], ADSL2+ [26] and VDSL [27] have all extended the basic ADSL specification to improve the bit-rate, although invariably this has been associated with even shorter useable distances. For example, with ADSL+ the maximum bit-rate of 24Mbit/s would only be achievable for those households that are within about 1km of the exchange.

Providing increased bit-rates for the consumer therefore requires extending the fibre network closer to the home to reduce the length of the twisted pair connection. BT is in the process of deploying Fibre to the Cabinet (FTTC) technology, with VDSL from the street cabinet to the home, capable of offering speeds of up to 40Mbit/s. BT predicts that 67% of the UK will be able to receive this FTTC/VDSL service by the end of 2015.

Ultimately, the external twisted pair network could be replaced entirely by fibre: a topology known as Fibre to the Premises (FTTP) or Fibre to the Home (FTTH). For example, there is such a network deployed in Sweden, offering access speeds of up to 100Mbit/s in each direction. The greatest penetration of FTTP and FTTH is still in the Asia-Pacific region, with South Korea, Hong Kong and Japan leading the penetration rates published by the FTTH Council [28].

6.1.2.2 Cable Networks

Hybrid Fibre-Coax (HFC) cable networks, were originally designed and installed to carry analogue TV services in an 8 MHz bandwidth channel. They can be used to provide broadband data services using one of the DOCSIS or EuroDOCSIS standards via a cable modem in the customer premises, often incorporated in the main TV Set Top Box, and a Cable Modem Termination System at the cable head-end. A benefit of the HFC solution is that performance does not degrade significantly with distance, so all consumers can be offered the same level of service.

EuroDOCSIS 2.0 [29] uses an 8MHz band of spectrum that would originally have been allocated to a single analogue TV service in order to provide the downstream IP service. EuroDOCSIS 3.0 [30] increases the downstream broadband capacity by enabling up to four such channels to be bonded together.

Virgin Media is currently in the process of upgrading its network from EuroDOCSIS 2.0 to EuroDOCSIS 3.0. It has announced that it will offer download bit-rates up to 120Mbit/s in upgraded sections of the network.

6.1.3 Wireless

6.1.3.1 Mobile Telephony

The Global System for Mobile (GSM) communications system represents the 2nd generation of mobile telephony. It did not originally provide Internet data support, but enhancements followed to support data at speeds of up to 115kbit/s using General Packet Radio Service (GPRS) and up to 384kbit/s using Enhanced Data-rates for GSM Evolution (EDGE).

The 3rd generation or "3G" is based on a technology called Universal Mobile Telecommunications System (UMTS) and which includes data rates of up to 384kbit/s. Again, evolutionary enhancements have increased speeds up to 14.4Mbit/s in cases using High-Speed Packet Access (HSPA). However, as with all cellular data communications, the rate is shared with all other users of the cell and usable rate is typically a couple of orders of magnitude less than these headline figures. It therefore does not provide a sufficiently reliable basis for the delivery of broadcast quality television.

ITU has defined a set of criteria for the fourth generation of mobile communications, dubbed "4G". The current release of the 3GPP Long Term Evolution (LTE) does not fully meet these criteria, although an enhancement of it, known as LTE Advanced, is a candidate. LTE has a theoretical peak download of 100Mbit/s, which LTE Advanced extends to 1Gbit/s. This provides a potential basis for the delivery of broadcast quality television services, although it remains to be seen whether an adequate Quality of Service (QoS) could be maintained.

6.1.3.2 Wi-Fi

The Wi-Fi (IEEE 802.11) family of technologies is now the primary means of distributing broadband access around the home. IEEE 802.11n [32] provides a maximum rate of 600Mbit/s, however most current implementations limit bandwidth to 300Mb/s. Increasing numbers of digital television sets with Internet TV service capability are becoming available with Wi-Fi nodes, or with USB ports to allow Wi-Fi nodes to be added.

Network operators also offer hotspot services in public areas such as airports, hotels and other public places in urban areas. It is also possible to use Wi-Fi to provide wireless broadband coverage across a large area through a coordinated deployment of multiple access points in public locations, such as that planned for London in time for the Olympic Games.

6.1.3.3 WiMAX

The WiMAX Forum is an industry-led organisation that has been formed to certify and promote the interoperability of broadband wireless products based upon IEEE 802.16 [33].

The 802.16 specifications apply across a wide range of the RF spectrum, and WiMAX could function on any frequency below 66 GHz. There is no uniform global licensed spectrum for WiMAX, and gaining access to sufficient harmonised spectrum across enough territories to enable the roaming that mobile users would expect is a major challenge. In an effort to increase interoperability and decrease cost, the WiMAX Forum has published three licensed spectrum profiles: 2.3 GHz, 2.5 GHz and 3.5 GHz.

6.1.3.4 White Spaces

TV "White Spaces" is a term used to refer to parts of the UHF spectrum which are not used by broadcast TV signals in a particular location. Low power location-sensitive devices, such as laptops, tablets and smart phones, could use this locally unused spectrum to access mobile data services.

A critical component of White Spaces systems is the database of available frequencies for particular locations. There is currently no agreed international technical standard for white spaces radios and several technological options are being explored. Some small-scale implementation of White Spaces has begun in the US. In Europe, several trials are being carried out, particularly in Munich and Cambridge, exploring issues such as White Spaces technology performance and potential interference to broadcasting.

6.1.4 Conclusions on Broadband IP Networks

Wired broadband IP networks can be expected to be an increasingly important mechanism for delivering audio-visual content to the home, enabling the delivery of TV and other audio-visual content at increasing levels of quality over both managed and unmanaged IP networks (see section 6.2 below).

Wireless networks are convenient for delivering content to mobile devices, such as tablets, laptops and smart phones. Wireless technology may also play an important role in providing broadband access in situations where it is economically difficult to justify installing a wired network, such as the last mile in rural areas.

Although the details of the technologies continue to evolve over time, wired reception looks likely to continue to retain an order of magnitude advantage over wireless in download bit-rate. The bit-rates of both appear to be increasing by around an order of magnitude every 5 years, as illustrated in Figure 10 below (Copyright ©2011 Rysavy Research, from "Mobile Broadband Explosion" report September 2011 [31]).

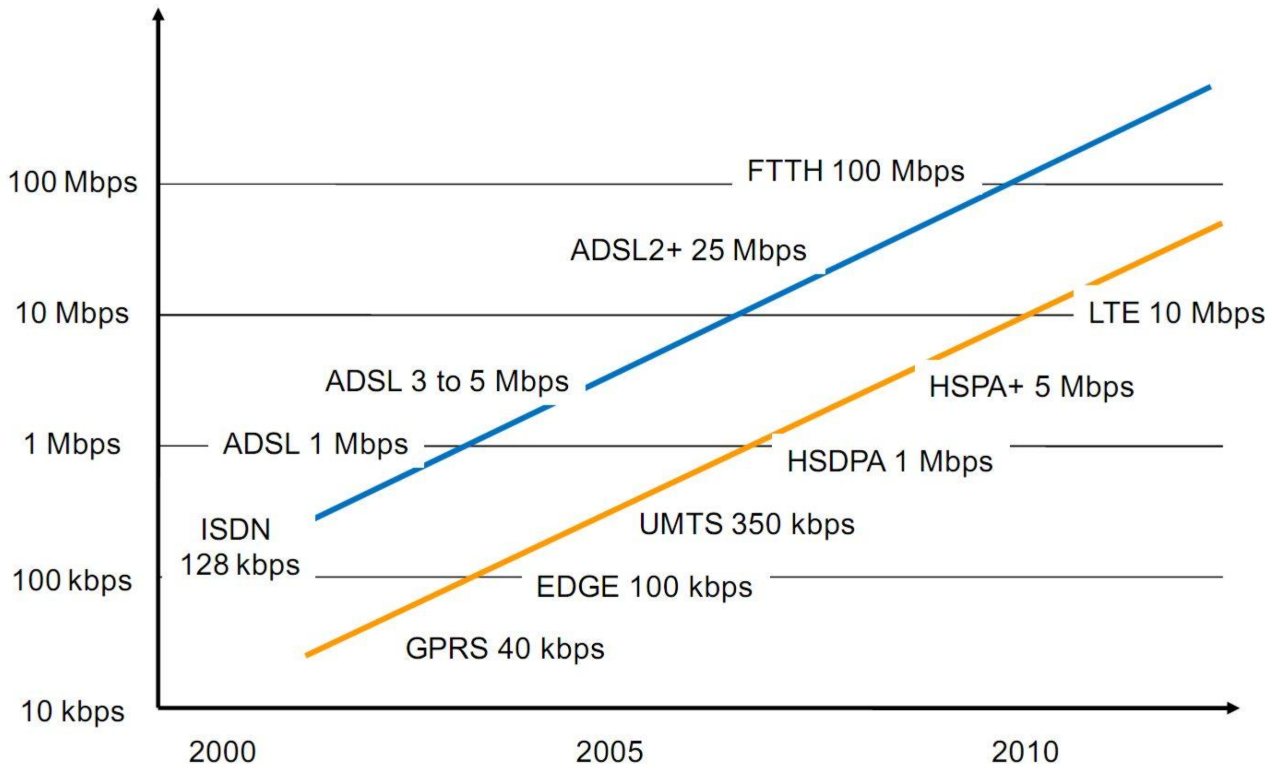


Figure 10: Broadband Data Rate over Time

6.2 TV delivery over IP

6.2.1 Overview

The delivery of television over IP networks falls into one of two broad categories:

1. IPTV over managed IP networks
2. Streamed TV over the unmanaged Internet

There are a number of major differences between the service offering in these two categories, despite the fact that both are based on the principles of the Internet Protocol.

6.2.2 Managed IPTV

Managed IPTV refers to IP networks that benefit from Quality of Service (QoS) mechanisms. Delivery of any service is undertaken only where there is a reasonable expectation that the network will deliver the service quality required. The primary mechanisms used are:

- IEEE 802.1p [34] at network layer 2 (packet transport prioritisation = Class Of Service)
- Differentiated Services at layer 3 (non-policy based QoS)

The managed networks are partitioned off from the wider Internet, so that all traffic in the network is controlled by the network operator. This allows the operator to ensure the network is not overloaded for services for which they wish to maintain QoS. Services such as IPTV tend to be carefully managed, while general Internet traffic (web browsing, e-mail, etc.) tend not to be. To deliver streamed IPTV services efficiently, these managed networks support broadcast-type IP functionality: User Datagram Protocol (UDP) with support for IP multicast.

The primary example of IPTV operation in the UK is the BT Vision IPTV/DVB-T hybrid service. This service uses Microsoft's IPTV Mediaroom platform, based on the Real Time Protocol (RTP) layered on top of UDP/IP. Real Time Streaming Protocol (RTSP) is generally used to manage the streaming delivery of the service. Ofcom reports [41] that the take-up of IPTV is highest in France, where it increased by almost a third during 2010 to reach 24% of French main television sets, making it the second most popular platform after DTT. There are 28 channels of HDTV carried by IPTV in France, compared to none in the UK.

The overall customer proposition for a managed IPTV service is roughly comparable to that of a satellite or cable subscription service. A major strength of IPTV is the integration of broadband Internet services, facilitating on-demand access to films, TV programmes music, etc. A historical weakness of IPTV is the forward path bandwidth available for live content, which has led to the popularity of offering hybrid IPTV/terrestrial TV services. It is expected that this weakness will disappear in the next few years due to the rapid rate of improvement in the capabilities of broadband IP networks (see section 6.1 above).

6.2.3 Unmanaged Internet services

Services delivered via the wider Internet cannot rely on an operator to manage the overall quality of service. Consequently, any service that requires an expectation of quality must use other approaches to ensure data gets through in a timely manner. The use of IP multicast on the Internet is currently unreliable, as it is not necessarily implemented in all switches and routers in the path. However, there are a range of alternative approaches available, including progressive download and HTTP adaptive streaming.

Progressive download is designed to allow the portion of content already downloaded to begin playing partway through the download process. This provides an effective means to deliver near-live content over imperfect connections; the key issue is that the average rate of download should exceed the speed of consumption of the data during playback or that playback be initiated only after a sufficient proportion of the download is complete to ensure playback cannot catch up with the download progress.

Progressive download is a primary component of the emerging Digital Television Group (DTG) specifications, with contributions from a number of service providers, including the BBC (using iPlayer), ITV (using ITVPlayer), Sky (using SkyPlayer), Channel 4 (4oD), Channel 5 (Demand 5), and others. iPlayer is moving into an ever-wider range of consumer devices such as STBs, TVs, games consoles, DVD players, tablets and smart phones. Peak data rates from the BBC iPlayer servers already reach 100Gbit/s and there is a clear trend of increasing usage.

HTTP adaptive streaming is another component of the emerging DTG specifications. The current lack of consistent quality for Internet connections means that it has not yet been widely used for the delivery of TV-like content. However, network operators will continue to include more generally applicable HTTP streaming mechanisms that support adaptive live streaming.

Adaptive streaming has already been adopted by Internet broadcasters, who are often service providers with international reach, such as YouTube. Traditional broadcasters are increasingly interested in providing so-called Over-The-Top services, i.e. extensions of their traditional broadcast offerings to provide catch-up TV, on-demand playback or additional material. However, it is likely to be some time before delivery over unmanaged IP networks is able to compete with the video quality offered by managed IP networks and the terrestrial, satellite and cable TV broadcasting mechanisms.

6.3 TV Broadcasting via Satellite

6.3.1.1 Channel Coding and Modulation for Satellite

DVB-S [10] is DVB's original satellite broadcasting specification. In 2003 DVB initiated a project to define a second generation of digital coding and modulation for satellite: DVB-S2 [11]. A key new component of this standard is the improved error correction offered by Low Density Parity Check (LDPC) codes. Along with other changes, this resulted in a performance improvement of around 35% greater data capacity or 2.5dB better signal-to-noise performance compared to the earlier systems.

For example, a typical 36 MHz satellite transponder operating at an EIRP of 51dBW may use:

- Symbol rate of 30.9 Mbaud
- QPSK modulation
- 3/4 FEC Rate

This combination gives a useful data rate of 46 Mbit/s, i.e. about 36% greater than DVB-S for the equivalent signal-to-noise requirements. In general, the performance of DVB-S2 is so close to the Shannon limit that there is limited potential for further improvements.

6.3.2 Satellite Broadcasting Platform

The inherent strengths of the satellite broadcasting platform are the high bandwidth of the forward path and the relatively low cost of providing and operating a broadcasting infrastructure that can serve a large majority of UK households. The main weakness is that broadband network access is not automatically included.

The satellite broadcasting platform is split between viewers who subscribe to BSkyB's pay TV services and free TV viewers. There are currently four main categories of free satellite viewer:

- those who have churned from BSkyB's pay services but have retained their satellite equipment so that they can continue to receive free-to-view channels
- users of BSkyB's own non-subscription services including "Freesat from Sky"
- homes taking the freesat service offered by the BBC and ITV
- users of satellite-receiving equipment from suppliers other than Sky or freesat

According to Ofcom's consumer research results for Q1 2011 [35], consumers in around 2.0 million homes claimed to have access to some form of free-to-view digital satellite device in the home. This represented an increase of around 0.7 million over a twelve month period. Ofcom's Q1 2011 survey also indicated that almost 9.3 million homes in the UK received BSkyB's pay satellite TV services, about the same as the Q1 2010 figure.

BSkyB has played a leading role in the introduction of HDTV to the UK and the BSkyB 2011 annual report [36] mentions the carriage of 54 HDTV channels. BSkyB is also playing a pioneering role in 3D TV with a dedicated Sky 3D channel. It is logical to expect that BSkyB will continue to exploit the competitive advantage of its high bandwidth forward path in the future by offering 1080p resolution services as soon as this is practical. It is therefore probable that 1080p services will start to become available on satellite platforms by 2015.

6.4 TV Broadcasting via Cable

6.4.1.1 Channel Coding and Modulation for Cable

The last of the DVB transmission systems to have its second generation defined was cable, with the DVB-C2 [15] specification being approved in March 2009. The original DVB-C [14] specification was a single carrier modulation system with modulation constellations up to 256QAM. DVB-C2 uses a COFDM approach with modulation constellations of up to 4096QAM per carrier. The COFDM modulation scheme is insensitive to echoes caused by typical in-house coaxial networks and is not sensitive to impulsive noise interference.

DVB-C2 gives more than a 30% improvement in spectrum efficiency under the same conditions as DVB-C deployments, potentially increasing to about 60% improvement for an optimised HFC network after analogue switch-off. The performance of DVB-C2 is so close to the Shannon limit that there is limited potential for further improvements.

6.4.2 Cable Broadcasting Platform

A major strength of the cable broadcasting platform is the integration of broadband IP services based on the Hybrid Fibre-Coax (HFC) network. This is inherently more robust than telecommunication networks based on twisted pairs of copper wires, as can be seen by comparing the bit-rates currently available via the EuroDOCSIS 3.0 cable modem (see section 6.1.2.2) with the currently deployed xDSL modems. The main weakness of the cable broadcasting platform is that the addressable market is limited to the homes passed by the network, approximately 13 million according to the 2010 Virgin Media Annual Report [37].

Ofcom's consumer research results for Q1 2011 [35] show that 3.4 million homes took cable television, an increase of about 0.1 million over the previous 12 months.

Virgin Media is playing to the strengths of its network by offering an extensive video-on-demand (VOD) service, Virgin TV On Demand. The 2010 Annual Report stated that VOD usage increased from 68 million average monthly views in Q1 2010 to 87 million in Q4 2010. The number of HDTV services available on cable is significantly less than on satellite (19 rather than 54), due to the more limited capacity of the cable platform. This situation will be alleviated when Virgin Media finally make the transition to H.264/AVC coding (see section 3.1.1); they are the last major broadcaster in Europe to still use MPEG-2 for HDTV. There is further potential to increase capacity by making the transition from DVB-C to DVB-C2 channel coding and modulation (see section 6.4.1.1 above). In Germany, Kabel Deutschland has announced that it will start DVB-C2 services in mid 2012.

It is therefore probable that 1080p services will start to become available on cable shortly after they become available on the satellite platform.

7 Spectrum Issues

7.1 Overview

The total amount of spectrum available for DTT may change over time. On the one hand, extra spectrum may become available for DTT services after digital switch-over (DSO). On the other hand, DTT spectrum may re-assigned to other services, such as mobile broadband. The competitiveness of the DTT platform is related to the number of programme channels carried, which in turn depends on the amount of UHF spectrum available.

Ofcom is seeking to develop a framework for the long term future of UHF spectrum [43], in order to better understand the future demand for the UHF spectrum by different services. This framework will be used to inform approach to policy decisions such as:

- "the on-going licensing of the UHF spectrum, including the 600 MHz spectrum released by DSO, and whether this should enable a future opportunity to make adjustments to the allocation of the UHF spectrum between different service types;
- the future availability of spectrum for wireless broadband which is expected to be raised at the 2012 World Radio Conference (WRC 12) with a view to its inclusion on the agenda of the following WRC in 2015/16, including possible discussion of a co-primary allocation to broadcast and mobile services in the 700 MHz band."

It should be noted that a spectrum planning study is a major exercise in itself, which is beyond the scope of this report.

7.2 Digital Switch-Over

In the UK, there are 2 main frequency bands that are planned to be released as part of the cleared spectrum following digital switch-over (DSO):

- the "600MHz" band (UHF channels 31 to 37, from 550 to 606 MHz), currently deployed across Europe for terrestrial television broadcasting services. Potential uses after DSO could include DTT, mobile broadband, mobile TV, programme making and special events (PMSE), etc.
- the "800MHz" band (UHF channels 61 to 69, from 790 to 862 MHz), harmonised throughout Europe to be allocated to mobile broadband use after DSO

The remaining UHF channels (21 to 30 and 39 to 60) are part of the "interleaved" spectrum capacity available that will be used after DSO to carry the existing 6 DTT multiplexes.

The "600MHz" band is being cleared through DSO and could be available from 2013. Following a consultation, Ofcom indicated in September 2011 [44] that the provision of new DTT multiplexes is a possible use for this spectrum.

The parameters defined for each of the multiplexes are referred to as 'Layers' within the context of the UK Frequency Plan (where 6 multiplexes i.e. six 'Layers' already exist). A reference transmission plan carried out by Arqiva [45] assumes "Layers" 7 and 8 would each be based on the use of three UHF channels: channels 31, 32 and 33 for Layer 7, channels 34, 35 and 37 for Layer 8. Layer 9 would use UHF channel 36 as a national single-frequency network.

The scenarios examined in Section 8 will therefore include the possibility that the number of DTT multiplexes would be increased by 3 after DSO. If the spectrum was awarded in 2013, it would probably be around 2015 before the new infrastructure was installed and operational.

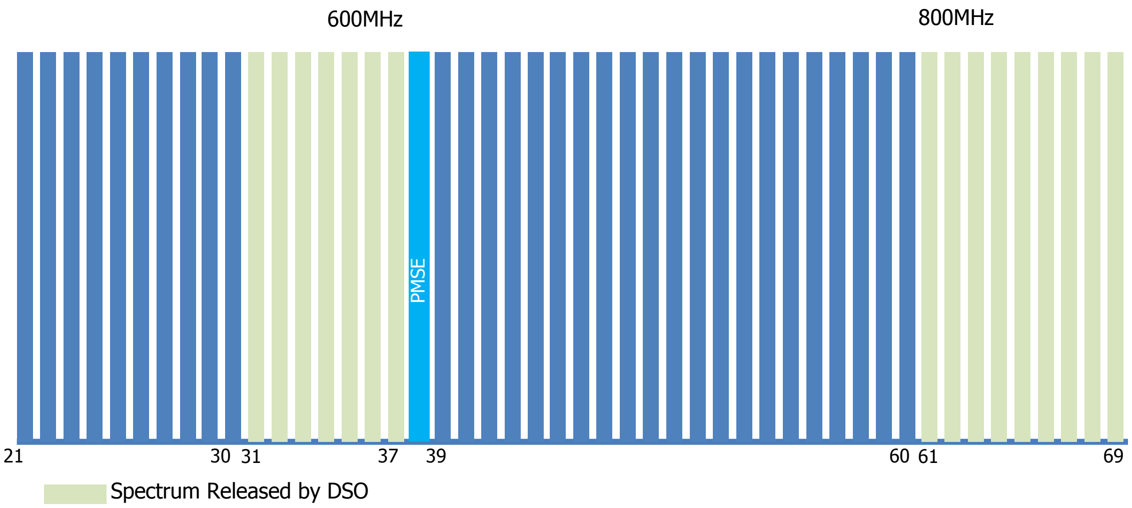


Figure 11: UHF Spectrum Released in Bands IV and V by Digital Switch-Over

7.3 Future Spectrum re-Planning

The Asia-Pacific Telecommunity (APT), which includes Australia, China, Japan, South Korea and other countries in the Asia Pacific Region, agreed on a plan to assign the 698-806 MHz frequency range to mobile broadband in September 2010. There appears to be increasing interest in using this plan as the basis of an internationally harmonised approach for mobile broadband, to enable better economies of scale and facilitate global roaming.

If this band were also to be assigned to mobile broadband in Europe, it would necessarily involve a reduction in the spectrum available to DTT. Given the lengthy timescales normally required for international frequency coordination, it is assumed that this would take place after 2020, most probably around 2025. The scenarios examined in Section 8 therefore include the possibility that the number of DTT multiplexes would be decreased by 3 from 2025.

8 Scenarios for DTT platform development

8.1 Assumptions for Scenarios

8.1.1 1st Generation Services

1st Generation services consist of SDTV video content encoded using MPEG-2 and carried on 5 DVB-T multiplexes. The PSB multiplexes have a capacity of 24.1 Mbit/s, whilst the commercial multiplexes use slightly less robust transmission parameters to give a capacity of 27.1 Mbit/s.

Approximately 1.5 Mbit/s is required for non-programme content: MPEG Program Specific Information (PSI) [1], DVB Service Information (SI) [8][9], interactive data, null packets etc. The remaining 22.6 Mbit/s or 25.6 Mbit/s is available for programme content. Part of this capacity is currently used for radio services, but for ease of comparison this report will assume that all capacity for programme content is used for TV services (including programme related content such as subtitles and audio description).

The technology required to support 1st Generation services is now fairly mature. The scenarios in this report assume that no major improvement in MPEG-2 encoder efficiency will occur and that each 1st Generation PSB multiplex will carry 9 TV services and each 1st Generation commercial multiplex will carry 10 TV services throughout the period under consideration.

8.1.2 2nd Generation Services

2nd Generation services consist of 1080i or 720p HDTV video content encoded using H.264/AVC and carried on a DVB-T2 multiplex with a capacity of 40.2 Mbit/s. The scenarios assume that 1.5 Mbit/s is required to be set aside for non-programme content: MPEG Program Specific Information (PSI) [1], DVB Service Information (SI) [8][9], interactive data, null packets etc. The remaining 38.7 Mbit/s is available for programme content.

H.264/AVC encoders still continue to improve, but at a slower rate than occurred in the first few years after the initial services were launched. The scenarios in this report assume that the number of HDTV services per multiplex will increase from four in 2010 to five in 2015, before reaching a plateau of six in 2020. The change in the number of services per multiplex is summarised in Table 4 below, which also shows the equivalent constant bitrate (CBR) per service, assuming the statistical multiplex gain described in Section 3.3.2.

	Number of 720p or 1080i services per mux	Equivalent CBR bitrate per service	Assumed Stat Mux Gain
2010	4	11.4 Mbit/s	15.0%
2015	5	9.4 Mbit/s	17.5%
2020	6	8.0 Mbit/s	19.5%
2025	6	8.0 Mbit/s	19.5%
2030	6	8.0 Mbit/s	19.5%

Table 4: Number of 2nd Generation Services per Multiplex

8.1.3 3rd Generation Services

3rd Generation services consist of 1080p or 720p HDTV video content encoded using HEVC and carried on a DVB-T2 multiplex with a capacity of 40.2 Mbit/s. The scenarios assume that 1.5 Mbit/s is required to be set aside for non-programme content: SI/PSI, interactive data, null packets etc. The remaining 38.7 Mbit/s is available for programme content.

HEVC encoders are expected to become available in 2014 and to rapidly improve in compression efficiency in the first few years before reaching a plateau by about 2030. The change in the number of 1080p services per multiplex is summarised in Table 5 below, which also shows the equivalent constant bitrate (CBR) per service, assuming the statistical multiplex gain described in Section 3.3.2.

	Number of 1080p services per mux	Equivalent CBR bitrate per service	Assumed Stat Mux Gain
2010	-	-	-
2015	5	9.4 Mbit/s	17.5%
2020	8	6.3 Mbit/s	23.0%
2025	9	5.7 Mbit/s	24.0%
2030	10	5.2 Mbit/s	25.0%

Table 5: Number of 1080p 3rd Generation Services per Multiplex

Some of the 3rd Generation services with smaller audiences may be based on the 720p video format rather than 1080p, in order to increase the total number of services whilst maintaining a level of video quality that is similar to the current HDTV services. The improvement in technology since the 1st Generation means that even in 2015 it should be possible to provide a larger number of 720p services in a 3rd Generation multiplex than SDTV services in a 1st Generation multiplex. The number of 720p services per multiplex will then increase further in subsequent years, as summarised in Table 6 below.

	Number of 720p services per mux	Equivalent CBR bitrate per service	Assumed Stat Mux Gain
2010	-	-	-
2015	11	4.7 Mbit/s	25.8%
2020	17	3.2 Mbit/s	28.5%
2025	19	2.9 Mbit/s	28.7%
2030	21	2.6 Mbit/s	28.9%

Table 6: Number of 720p 3rd Generation Services per Multiplex

8.2 Description of Scenarios to be Evaluated

A major distinction between the scenarios in section 8.3 of this report is the speed at which transitions from one generation to the next are managed: the roll-out of 3rd Generation services and the speed with which 1st Generation services are phased out. In most scenarios, it is assumed that 1st Generation services are concentrated on one or two "legacy" multiplexes by 2020. Four alternatives are considered for the timing of transitions:

A. Roll-out of 3rd Generation services in 2015, 1st Generation services switched off in 2025
B. Roll-out of 3rd Generation services in 2015, 1st Generation services switched off in 2030
C. Roll-out of 3rd Generation services in 2020, 1st Generation services switched off in 2030
D. No Roll-out of 3rd Generation services, 1st Generation services switched off in 2030

For simplicity, the scenarios assume that entire multiplexes are switched over at a time. However, since 2nd and 3rd Generation services both use DVB-T2, some fine-tuning of scenarios would be possible at the level of individual programmes within a multiplex.

As noted in section 8.1.3, some 3rd Generation services may use 720p rather than the 1080p video format. The two extreme examples of all 1080p and all 720p are quantified in the scenarios. In practice it is probable that there would be a mixture of formats, with major channels being broadcast as 1080p whilst channels of minority interest would be 720p.

There is no explicit consideration of stereoscopic 3D services in the scenarios. It is assumed that such services will remain a relatively minor part of the total programme offering and hence will not have a significant effect on the overall DTT bit-rate requirement. For example, if there were two dedicated 3D channels then it would reduce the total number of channels by one, since the two 3D channels would require a similar bit-rate to three normal channels.

As noted in section 7, the total amount of spectrum available for DTT may change over time. On the one hand, extra spectrum may become available for DTT services after analogue switch-off. On the other hand, DTT spectrum may re-assigned to other services, such as mobile broadband. Three possibilities for spectral usage are considered:

1. DTT reducing to 3 multiplexes from 2025
2. DTT remaining at 6 multiplexes throughout the period under consideration
3. DTT increasing to 9 multiplexes in 2015, dropping back to 6 in 2025

Combined with the four alternatives for the timing of transitions, this results in a total of 12 scenarios. These scenarios are summarised in Table 7 below and evaluated in section 8.3:

Scenarios	3 multiplexes	6 multiplexes	9 multiplexes
3rd Gen services launched in 2015, 1st Gen services switched off in 2025	A1	A2	A3
3rd Gen services launched in 2015, 1st Gen services switched off in 2030	B1	B2	B3
3rd Gen services launched in 2020, 1st Gen services switched off in 2030	C1	C2	C3
No Roll-out of 3rd Gen services, 1st Gen services switched off in 2030	D1	D2	D3

Table 7: Overview of the Scenarios Considered

8.3 Scenarios

8.3.1 Scenario A1

In Scenario A1, 3rd Generation services are launched in 2015, 1st Generation services are switched off in 2025 and 2nd Generation services are switched off in 2030. It is also assumed that the DTT capacity is reduced to 3 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 8 below.

Pros:

The advantage of this scenario is that more spectrum would be available for other uses from 2025.

Cons:

The disadvantage of this scenario is that DTT would be unlikely to remain competitive with alternative TV platforms after 2025. In 2025 there would be only 18 DTT channels at 1080p resolution (or 38 channels at 720p resolution), plus 6 legacy channels using 2nd Generation technology.

After switching off 1st and 2nd Generation services in 2030 this would increase to 30 DTT channels at 1080p resolution (or 63 channels at 720p resolution).

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**5** channels *1 mux*	**5** (11) channels *1 mux*
2020	-	**28** channels *3 mux*	**6** channels *1 mux*	**16** (34) channels *2 mux*
2025	-	-	**6** channels *1 mux*	**18** (38) channels *2 mux*
2030	-	-	-	**30** (63) channels *3 mux*

Table 8: Scenario A1

8.3.2 Scenario A2

In Scenario A2, 3rd Generation services are launched in 2015, 1st Generation services are switched off in 2025 and 2nd Generation services are switched off in 2030. It is assumed that the DTT capacity remains at 6 multiplexes throughout the period under consideration. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 9 below.

Pros:

The advantage of this scenario is that DTT remains competitive in the long term, with 60 channels of 1080p (or 126 channels of 720p) in 2030.

It is assumed that 2nd Generation services would remain concentrated on a single multiplex. An alternative strategy could be to use some additional capacity to allow an expansion of 2nd Generation services during the period from 2020 to 2025. However, this would then create more of 2nd Generation legacy problem, which could inhibit take-up of 3rd Generation equipment and make it more difficult to complete the transition to 3rd Generation services by 2030.

Cons:

The disadvantage of this scenario relates to the period of triple-casting from 2015 to 2025. The number of SDTV channels would need to be reduced to 38 in 2015, in order to free a multiplex to allow the launch of 3rd Generation services.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**5** channels *1 mux*	**5** (11) channels *1 mux*
2020	-	**9**channels *1 mux*	**6** channels *1 mux*	**32** (68) channels *4 mux*
2025	-	-	**6** channels *1 mux*	**45** (95) channels *5 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 9: Scenario A2

8.3.3 Scenario A3

In Scenario A3, 3rd Generation services are launched in 2015, 1st Generation services are switched off in 2025 and 2nd Generation services are switched off in 2030. It is assumed that the DTT capacity is temporarily increased to 9 multiplexes in 2015 before reverting back to 6 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 10 below.

Pros:

The advantage of this scenario is that DTT remains competitive throughout the period under consideration. The temporary availability of the extra multiplexes during the triple-casting period avoids the need for any early trimming back of SDTV services and also allows the initial 3rd Generation service offering to be more attractive, thus giving more consumer incentive to buy new equipment.

An alternative strategy could be to use some additional capacity to allow some more expansion of 2nd Generation services during the period from 2015 to 2025. However, this would then create more of 2nd Generation legacy problem, which could inhibit take-up of 3rd Generation equipment and make it more difficult to complete the transition to 3rd Generation services by 2030.

Cons:

The disadvantage of this scenario is the greater demand on spectrum for DTT from 2015 to 2025, which could otherwise be used for other purposes.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**48** channels *5 mux*	**5** channels *1 mux*	**15** (33) channels *3 mux*
2020	-	**18** channels *2 mux*	**6** channels *1 mux*	**48** (102) channels *6 mux*
2025	-	-	**6** channels *1 mux*	**45** (95) channels *5 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 10: Scenario A3

8.3.4 Scenario B1

In Scenario B1, 3rd Generation services are launched in 2015, 1st and 2nd Generation services Generation services are both switched off in 2030. It is also assumed that the DTT capacity is reduced to 3 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 11 below.

Pros:

The advantage of this scenario is that more spectrum would be available for other uses from 2025.

Cons:

The main disadvantage of this scenario is that DTT would be unlikely to remain competitive with alternative TV platforms after 2025, particularly during the period of triple-casting on only 3 multiplexes between 2025 and 2030.

After switching off 1st and 2nd Generation services in 2030 there would be 30 DTT channels at 1080p resolution (or 63 channels at 720p resolution).

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**5** channels *1 mux*	**5** (11) channels *1 mux*
2020	-	**28** channels *3 mux*	**6** channels *1 mux*	**16** (34) channels *2 mux*
2025	-	**9** channels *1 mux*	**6** channels *1 mux*	**9** (19) channels *1 mux*
2030	-	-	-	**30** (63) channels *3 mux*

Table 11: Scenario B1

8.3.5 Scenario B2

In Scenario B2, 3rd Generation services are launched in 2015, 1st and 2nd Generation services Generation services are both switched off in 2030. It is assumed that the DTT capacity remains at 6 multiplexes throughout the period under consideration. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 12 below.

Pros:

The advantage of this scenario is that DTT remains competitive in the long term, with 60 channels of 1080p (or 126 channels of 720p) in 2030.

It is assumed that 2nd Generation services would remain concentrated on a single multiplex. An alternative strategy could be to use some additional capacity to allow an expansion of 2nd Generation services during the period from 2020 to 2025. However, this would then create more of 2nd Generation legacy problem, which could inhibit take-up of 3rd Generation equipment and make it more difficult to complete the transition to 3rd Generation services by 2030.

Cons:

The disadvantage of this scenario relates to the period of triple-casting from 2015 to 2030. The number of SDTV channels would need to be reduced to 40 in 2015, in order to free a multiplex to allow the launch of 3rd Generation services. Compared to scenario A2, the continuation of 1st Generation services until 2030 limits the potential for increasing the number of 3rd Generation services in 2025.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**5** channels *1 mux*	**5** (11) channels *1 mux*
2020	-	**8** channels *1 mux*	**6** channels *1 mux*	**32** (68) channels *4 mux*
2025	-	**9** channels *1 mux*	**6** channels *1 mux*	**36** (76) channels *4 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 12: Scenario B2

8.3.6 Scenario B3

In Scenario B3, 3rd Generation services are launched in 2015, 1st and 2nd Generation services Generation services are both switched off in 2030. It is assumed that the DTT capacity is temporarily increased to 9 multiplexes in 2015 before reverting back to 6 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 13 below.

Pros:

The advantage of this scenario is that DTT remains reasonably competitive throughout the period under consideration. The temporary availability of the extra multiplexes during most of the triple-casting period avoids the need for any early trimming back of SDTV services and also allows the initial 3rd Generation service offering to be more attractive.

An alternative strategy could be to use some additional capacity to allow some more expansion of 2nd Generation services during the period from 2015 to 2025. However, this would then create more of 2nd Generation legacy problem, which could inhibit take-up of 3rd Generation equipment and make it more difficult to complete the transition to 3rd Generation services by 2030.

Cons:

The main disadvantage of this scenario is the greater demand on spectrum for DTT from 2015 to 2025, which could otherwise be used for other purposes. Compared to scenario A3, the continuation of 1st Generation services until 2030 requires a reduction in the number of 3rd Generation services in 2025.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**48** channels *5 mux*	**5** channels *1 mux*	**15** (33) channels *3 mux*
2020	-	**48** channels *2 mux*	**6** channels *1 mux*	**48** (102) channels *6 mux*
2025	-	**9** channels *1 mux*	**6** channels *1 mux*	**36** (76) channels *4 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 13: Scenario B3

8.3.7 Scenario C1

In Scenario C1, 3rd Generation services are launched in 2020, 1st and 2nd Generation services Generation services are both switched off in 2030. It is also assumed that the DTT capacity is reduced to 3 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 14 below.

Pros:

The advantage of this scenario is that more spectrum would be available for other uses from 2025.

Cons:

The main disadvantage of this scenario is that DTT would be unlikely to remain competitive with alternative TV platforms after 2025, particularly during the triple-casting period on 3 multiplexes between 2025 and 2030.

After switching off 1st and 2nd Generation services in 2030 there would be 30 DTT channels at 1080p resolution (or 63 channels at 720p resolution).

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**10** channels *2 mux*	-
2020	-	**18** channels *2 mux*	**12** channels *2 mux*	**16** (34) channels *2 mux*
2025	-	**9** channels *1 mux*	**6** channels *1 mux*	**9** (19) channels *1 mux*
2030	-	-	-	**30** (63) channels *3 mux*

Table 14: Scenario C1

8.3.8 Scenario C2

In Scenario C2, 3rd Generation services are launched in 2020, 1st and 2nd Generation services Generation services are both switched off in 2030. It is assumed that the DTT capacity remains at 6 multiplexes throughout the period under consideration. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 15 below.

Pros:

The advantage of this scenario is that DTT remains competitive in the long term, with 60 channels of 1080p (or 126 channels of 720p) in 2030.

It is also relatively attractive in the short term, since a reduction of the number of SDTV services to 38 channels in 2015 would allow an early expansion of the number of HDTV services.

Cons:

The main disadvantage of this scenario is the reduction in the total number of services during the triple-casting period. The service offering during this transition period may not be competitive with other platforms.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**10** channels *2 mux*	-
2020	-	**9** channels *1 mux*	**12** channels *2 mux*	**24** (51) channels *3 mux*
2025	-	**9** channels *1 mux*	**6** channels *1 mux*	**36** (76) channels *4 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 15: Scenario C2

8.3.9 Scenario C3

In Scenario C3, 3rd Generation services are launched in 2020, 1st and 2nd Generation services Generation services are both switched off in 2030. It is also assumed that the DTT capacity is temporarily increased to 9 multiplexes in 2015 before reverting back to 6 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 16 below.

Pros:

The advantage of this scenario is that DTT remains competitive in the long term, with 60 channels of 1080p (or 126 channels of 720p) in 2030.

It is also attractive in the short term, since an early expansion of the number of HDTV services would be possible without requiring any reduction of the number of SDTV services.

Cons:

One disadvantage of this scenario is that the triple-casting period extends beyond the period when additional multiplexes are available. This results in a slight reduction in the total number of services between 2025 and 2030.

A further disadvantage is the greater demand on spectrum for DTT from 2015 to 2025, which could otherwise be used for other purposes.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**48** channels *5 mux*	**20** channels *4 mux*	-
2020	-	**18** channels *2 mux*	**12** channels *2 mux*	**40** (85) channels *5 mux*
2025	-	9 channels *1 mux*	**6** channels *1 mux*	**36** (76) channels *4 mux*
2030	-	-	-	**60** (126) channels *6 mux*

Table 16: Scenario C3

8.3.10 Scenario D1

In Scenario D1, there is no launch of 3rd Generation services during the period under consideration and 1st Generation services are switched off in 2030. It is also assumed that the DTT capacity is reduced to 3 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 17 below.

Pros:

The advantage of this scenario is that more spectrum would be available for other uses from 2025.

Cons:

The disadvantage of this scenario is that DTT would not be competitive with alternative TV platforms after 2025. In the simulcasting period from 2025 to 2030 there would be only 12 HDTV channels plus 9 legacy SDTV channels.

After the switchover to purely 2nd Generation services in 2030 the service offering would consist of 18 HDTV channels.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**10** channels *2 mux*	-
2020	-	**38** channels *4 mux*	**12** channels *2 mux*	-
2025	-	**9** channels *1 mux*	**12** channels *2 mux*	-
2030	-	-	**18** channels *3 mux*	-

Table 17: Scenario D1

8.3.11 Scenario D2

In Scenario D2, there is no launch of 3rd Generation services during the period under consideration and 1st Generation services are switched off in 2030. It is assumed that the DTT capacity remains at 6 multiplexes throughout the period under consideration. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 18 below.

Pros:

The advantage of this scenario is that there is no triple-casting period for DTT.

A reduction of the number of SDTV services to 38 channels in 2015 would allow an early expansion of the number of HDTV services.

Cons:

The disadvantage of this scenario is that DTT may not remain competitive with alternative TV platforms in the medium and longer term. In 2025 there would be 30 HDTV channels plus 9 legacy SDTV channels. After the switchover to purely 2nd Generation services in 2030 the service offering would consist of 36 HDTV channels.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**38** channels *4 mux*	**10** channels *2 mux*	-
2020	-	**9** channels *1 mux*	**30** channels *5 mux*	-
2025	-	**9** channels *1 mux*	**30** channels *5 mux*	-
2030	-	-	**36** channels *6 mux*	-

Table 18: Scenario D2

8.3.12 Scenario D3

In Scenario D3, there is no launch of 3rd Generation services during the period under consideration and 1st Generation services are switched off in 2030. It is assumed that the DTT capacity is temporarily increased to 9 multiplexes in 2015 before reverting back to 6 multiplexes in 2025. A possible evolution of the number of programme channels of each generation of technology is summarised in Table 19 below.

Pros:

The advantage of this scenario is that there is no triple-casting period for DTT, so the additional multiplexes would allow an early expansion of the number of HDTV services without requiring any reduction of the number of SDTV services. It is also relatively attractive in the medium term, since the reduction in the number of 1st Generation services can initially be relatively gradual.

Cons:

The disadvantage of this scenario is that DTT may not remain competitive with alternative TV platforms in the longer term. In 2025 there would be 30 HDTV channels plus 9 legacy SDTV channels. After the switchover to purely 2nd Generation services in 2030 the service offering would consist of 36 HDTV channels.

	Generation 0 Analogue TV	**Generation 1** Digital SDTV	**Generation 2** HDTV	**Generation 3** 1080p (720p)
2010	**5** channels	**48** channels *5 mux*	**4** channels *1 mux*	-
2015	-	**48** channels *5 mux*	**20** channels *4 mux*	-
2020	-	**38** channels *4 mux*	**30** channels *5 mux*	-
2025	-	**9** channels *1 mux*	**30** channels *5 mux*	-
2030	-	-	**36** channels *6 mux*	-

Table 19: Scenario D3

9 Governance Issues

The DTT platform in the UK is a horizontal market where any retailer can market the customer premises equipment (e.g. digital TV sets, digital set-top boxes) bearing the Freeview trademark and digital switchover certification mark.

Unlike the vertical cable or satellite platforms, DTT currently has no centralised platform management and no single player is able to control the entire ecosystem. The decision making process is relatively complex and any innovation relies on coordination and consensus among the many players involved: see Figure 12 below.

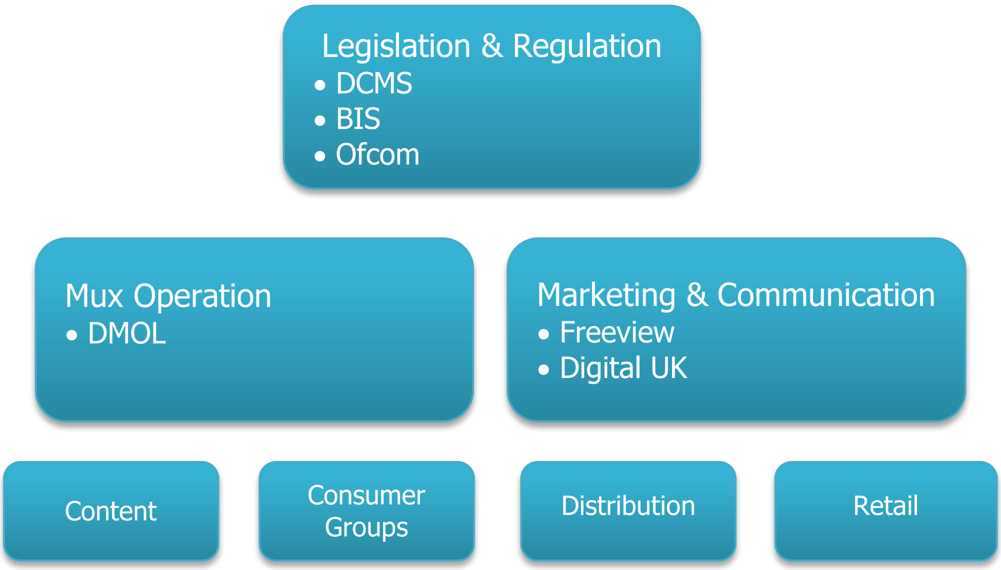


Figure 12: Overview of Current DTT Governance

Whilst keeping all key parties on the broadcasting chain included in the decision-making process is important, the process of self-coordination and decision by consensus is likely to make it more difficult to implement technology changes in a timely manner. In addition, incentives on these parties to bring changes about may not align adequately with the changes likely to maximise the benefits to consumers.

A more centralised and direct leadership, coupled with a simpler structure, could provide a clearer path to make decisions on improvements to the DTT platform and to minimise delays in their implementation. This could also help to provide more certainty to both equipment manufacturers and consumers, thus facilitating the process of adoption of new technology. This may help the DTT platform to remain competitive against satellite and cable pay TV platforms, which are able to implement upgrades and changes more dynamically due to their centralised platform control.

The timely transition between the various generations of DTT technologies is likely to be dependent on the extent to which the governance structure supports coordinated action by stakeholders.

10 Abbreviations

2D	Two Dimensional
3D	Three Dimensional
3GPP	3rd Generation Partnership Project
AAC	Advanced Audio Coding (ISO/IEC 14496-3)
AVC	Advanced Video Coding (ISO/IEC 14496-10 and ITU-T H.264)
ADSL	Asymmetric Digital Subscriber Line
AWGN	Additive white Gaussian noise
b	bit
B	Byte (8 bits)
CBR	Constant Bit-Rate
COFDM	Coded Orthogonal Frequency Division Multiplexing
DOCSIS	Data-Over-Cable Service Interface Specification
DSL	Digital Subscriber Line (as in xDSL)
DSO	Digital switch-over (from analogue)
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcasting
DVB-AVC	DVB Audio-Visual Coding
DVB-C	DVB specification for Cable Channel Coding and Modulation
DVB-C2	DVB specification for Cable Channel Coding and Modulation, 2nd Generation
DVB-H	DVB specification for Channel Coding and Modulation on Handheld (terrestrial)
DVB-S	DVB specification for Satellite Channel Coding and Modulation
DVB-S2	DVB specification for Satellite Channel Coding and Modulation, 2nd Generation
DVB-SH	DVB Satellite Handheld (hybrid satellite/terrestrial)
DVB-T	DVB specification for Terrestrial Channel Coding and Modulation
DVB-T2	DVB specification for Terrestrial Channel Coding and Modulation, 2nd Generation
DVD	Digital Versatile Disc (or Digital Video Disc)
EDGE	Enhanced Data-rates for GSM Evolution
EGPRS	Enhanced General Packet Radio Service
FC	Frame-Compatible (a method of stereoscopic 3D coding)
FEF	Future Extension Frames (in DVB-T2)
FTTC	Fibre to the Cabinet

FTTH	Fibre to the Home
FTTP	Fibre to the Premises
G	giga (prefix generally indicating 1,000,000,000 but see GB below for computing)
GB	GigaByte (2^{30} = 1,073,741,824 Bytes)
GSM	Global System for Mobile Communications
H.264/AVC	ITU-T H.264 / ISO/IEC 14496-10 (MPEG-4 Advanced Video Coding)
HDMI	High-Definition Multimedia Interface
HDTV	High Definition Television
HEVC	High Efficiency Video Coding
HFC	Hybrid Fibre-Coax
HSPA	High Speed Packet Access
IPTV	Internet Protocol Television
ISM	Industrial Scientific Medical frequency band
ISO	International Standardization Organization
JCT-VC	Joint Collaborative Team on Video Coding (joint between MPEG and VCEG)
k	kilo (prefix generally indicating 1,000 but see KB below for use in computing)
KB	KiloByte (2^{10} = 1,024 Bytes)
LCD	Liquid Crystal Display
LDPC	Low-density parity-check (in DVB-T2)
LTE	Long Term Evolution
M	mega (prefix generally indicating 1,000,000 but see MB below for computing)
MB	MegaByte (2^{20} = 1,048,576 Bytes)
MIMO	Multiple Input, Multiple Output
MPEG	Moving Pictures Experts Group (ISO/IEC JTC1/SC29/WG11)
MVC	Multiview Video Coding (of H.264/AVC)
OFDM	Orthogonal Frequency Division Multiplexing
PLP	Physical Layer Pipe (in DVB-T2)
PMSE	Programme making and special events
PSI	Program Specific Information (in MPEG-2 Transport Stream)
PSNR	Peak Signal-to-Noise Ratio
PVR	Personal Video Recorder
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency

SVC	Scalable Video Coding (of H.264/AVC)
SDTV	Standard Definition Television
SI	Service Information (defined by DVB)
STB	Set-top-box
TB	TeraByte (2^{40} = 1,099,511,627,776 Bytes)
UHD	Ultra High Definition
UHDTV	Ultra High Definition Television
UHF	Ultra High Frequency band
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VBR	Variable bit-rate
VCEG	Video Coding Experts Group (ITU-T Q.6/SG 16)
VDSL	Very high bitrate DSL
VOD	Video on Demand
Wi-Fi	Wireless Fidelity (IEEE 802.11)
WiMAX	Worldwide Interoperability for Microwave Access (IEEE 802.16)
WLAN	Wireless Local Area Network
WRC	World Radio Conference
xDSL	Generic term for the DSL family of standards

11 References

[1] ISO/IEC 13818-1 / ITU-T Recommendation H.222.0: "Information Technology - Generic Coding of moving pictures and associated audio information – Part 1: Systems"

[2] ISO/IEC 13818-2 / ITU-T Recommendation H.262: "Information Technology - Generic Coding of moving pictures and associated audio information - Part 2: Video"

[3] ISO/IEC 13818-3: "Information technology - Generic coding of moving picture and associated audio information – Part 3: Audio"

[4] ISO/IEC 14496-3 "Information technology - Coding of audio-visual objects - Part 3: Audio"

[5] ISO/IEC 14496-10 / ITU-T Recommendation H.264: "Information technology - Coding of audio-visual objects - Part 10: Advanced Video Coding"

[6] ETSI TS 102 366: "Digital Audio Compression (AC 3, Enhanced AC 3) Standard"

[7] ETSI TS 101 154: "Digital Video Broadcasting (DVB); Specification for the use of Video and Audio Coding in Broadcasting Applications based on the MPEG 2 Transport Stream"

[8] ETSI EN 300 468: "Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems"

[9] ETSI ETR 211: "Digital Video Broadcasting (DVB); Guidelines on implementation and usage of Service Information (SI)"

[10] EN 300 421 V1.1.2: "Framing structure, channel coding and modulation for 11/12 GHz satellite services" (DVB-S)

[11] EN 302 307 V1.2.1: "Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications" (DVB-S2)

[12] EN 300 744 V1.6.1: "Framing structure, channel coding and modulation for digital terrestrial television" (DVB-T)

[13] EN 302 755 V1.2.1: "Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system" (DVB-T2)

[14] EN 300 429 V1.2.1 "Framing structure, channel coding and modulation for cable systems" (DVB-C)

[15] EN 302 769 V1.2.1: "Frame structure channel coding and modulation for a second generation digital transmission system for cable systems" (DVB-C2)

[16] ITU-R Recommendation BT.709: "Parameter values for the HDTV standards for production and international programme exchange"

[17] IEC 61966-2-4: "Multimedia systems and equipment – Colour measurement and management – Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC"

[18] EBU Technical Report 005: "Information Paper on HDTV Formats", February 2010

[19] EBU Technical Report 3324: "EBU Evaluations of Multichannel Audio Codecs", September 2007

[20] "Results of a survey on television viewing distance", N. E. Tanton, BBC R&D White Paper, WHP 090, 2004

[21] "Tests of visual acuity to determine the resolution required of a television transmission system", J. O. Drewery and R. A. Salmon, BBC R&D White Paper, WHP 092, 2004

[22] "Beyond HDTV: Implications for Digital Delivery", Ken McCann, Jeff Gledhill, Adriana Mattei, Stuart Savage, Report by ZetaCast commissioned by Ofcom, July 2009

[23] "Compression Performance of High Efficiency Video Coding (HEVC) Working Draft 4", Bin Li, Gary J. Sullivan and Jizheng Xu, submitted to IEEE International Symposium on Circuits and Systems (ISCAS) 2012

[24] ITU-T G.992.1: "Asymmetric digital subscriber line (ADSL) transceivers"

[25] ITU-T G.992.3: "Asymmetric digital subscriber line transceivers 2 (ADSL2)"

[26] ITU-T G.992.5: "Asymmetric Digital Subscriber Line (ADSL) transceivers - Extended bandwidth ADSL2 (ADSL2plus)"

[27] ITU-T G.993.1: "Very high speed digital subscriber line transceivers"

[28] Press Release, "Global Fiber to the Home Expansion Defies the Economic Downturn", FTTH Council, September 2009

[29] ITU-T J.122: "Second-generation transmission systems for interactive cable television services - IP cable modems"

[30] ITU-T J.222: "Third-generation transmission systems for interactive cable television services - IP cable modems

[31] "Mobile Broadband Explosion" , Rysavy Research, September 2011

[32] IEEE 802.11n: "Local and Metropolitan Area Networks, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 5: Enhancements for Higher Throughput"

[33] IEEE 802.16: "Local and metropolitan area networks, Part 16: Air Interface for Broadband Wireless Access Systems"

[34] IEEE 802.1D: "Local and Metropolitan Area Networks, Media Access Control (MAC) Bridges"

[35] The Communications Market Digital Progress Report: Q1 2011, Ofcom, July 2011

[36] BSkyB Annual Report 2011

[37] Virgin Media Annual Report 2010

[38] "Global TV Replacement Study", DisplaySearch, 2011,

[39] Communications Market Report, Ofcom, August 2011

[40] "Report for the BBC Trust on the Model to Assess the Impact of Canvas on the TV Market", Value Partners, December 2009

[41] "International Communications Market Report 2011", Ofcom, December 2011

[42] "Understanding Gartner's Hype Cycles": Jackie Fenn, Mark Time, Harvard Business Press, 2008

[43] "Developing a framework for the long term future of UHF spectrum bands IV and V", Ofcom, April 2011

[44] "600 MHz award update, Next steps for award design and reference offer for digital terrestrial television", Ofcom, September 2011

[45] "Creation of Broadcast Layers 7, 8 and 9 in 600MHz released Spectrum", Study by Arqiva, September 2011