Digital TV Spectrum Requirements and the Digital Dividend

Briefing Note Prepared for GSM Association

ABSTRACT

The purpose of this note is to discuss the issues concerning the amount of radio spectrum required by terrestrial television services once they have migrated from analogue to digital transmission. This transition provides the opportunity to increase the capacity and quality of terrestrial television, whilst releasing valuable UHF spectrum for new and innovative services like mobile broadband.

The note explores the technical issues that influence the amount of spectrum required by broadcasters, as well as looking at what has happened in those markets that have moved from analogue to digital television.

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1 EXECUTIVE SUMMARY

1.1 Introduction

The planned switchover from analogue to digital TV broadcasting will provide a significant improvement in programme choice and picture quality for viewers. It will also provide the opportunity to release some of the radio spectrum currently used for TV broadcasting for other uses, such as expanding provision of mobile and wireless broadband services. These benefits arise from the more efficient way in which digital technology uses the available radio spectrum, compared with today's analogue services. This opportunity to release spectrum for new and innovative services like mobile broadband is known as the Digital Dividend.

Maximising these benefits will depend on making appropriate choices with regard to technology, network planning and frequency allocation, whilst ensuring that sufficient provision is made to meet anticipated future requirements for TV services. It will also require action to set a clear timescale for ceasing analogue transmission.

1.2 Realising the Digital Dividend

The spectrum that is currently used for terrestrial TV broadcasting is split into two parts, VHF, and UHF. In Asia for example the VHF band comprises eight 7 MHz frequency channels (i.e. 56 MHz of spectrum and the UHF band comprises forty nine 8 MHz channels, i.e. 392 MHz of spectrum. These large pieces of spectrum are ideally suited to providing cost-effective mobile and broadband wireless services and represent a very significant and important asset for any country's economic and social development. If frequencies above 698 MHz were made available for mobile broadband services that would still leave 27 UHF channels (216 MHz) and 8 VHF channels (56 MHz), i.e. 272 MHz in total. This is more spectrum than is currently reserved for digital TV in the UK, which is one of the world's most developed digital TV markets.

Work is currently being undertaken in the Asia-Pacific Telecommunity Wireless Forum (AWF), on the approach to harmonise the UHF band for mobile broadband. At the 2007 ITU World Radio Conference (WRC07), China and India both opted to be included in *ITU*-R footnote 5.313A, which effectively means they have signalled an intention to deploy mobile in 698 to 806 MHz. The work to date in AWF also suggests that 698 – 806 MHz is the preferred spectrum to seek an Asia Pacific wide sub-band for mobile broadband.

In Europe the band 790 – 862 MHz is currently planned to be made available in many markets. There is already a debate emerging about the need to consider a second sub-band going down to 698 MHz. This debate was initiated by work

commissioned by the European Commission[1] looking at exploiting the digital dividend.

This briefing note explains the efficiency improvements that digital television technology provides, how these can be maximised in practice and shows that a compelling terrestrial digital TV service can be delivered with substantially less radio spectrum than is currently used for analogue transmission. The benefits of releasing additional spectrum for mobile and wireless broadband services are also highlighted.

1.3 Conclusion

The spectrum that is available to broadcasters below 698 MHz amounts to some 27 UHF channels and 8 VHF channels[2]. The experience of European countries that have launched digital TV suggests that this should be sufficient to support seven or more national multiplexes. Currently available broadcast technology (DVB-T/MPEG4) can support up to 8 standard definition stations per multiplex, allowing for 56 or more TV stations to be broadcast. This would allow for the growth in broadcasting capacity needed to fund the transition from analogue to digital TV, and allow for a further digital dividend.

Freeing up spectrum above 698 MHz offers the opportunity for global harmonisation of the digital dividend for IMT. Such a global harmonisation of the band could offer substantial benefits in terms of economies of scale for mobile devices, as well as making international roaming easier.

[1] http://www.analysysmason.com/PageFiles/13359/Analysys%20Mason's%20public%20presentation%20of%20final%20results%2020090909.pdf

[2] Of 8 MHz channels

2 WHY IS DIGITAL BROADCASTING MORE EFFICIENT?

2.1 Limitations of Analogue Transmission

Analogue broadcasting can deliver only a single TV station on each 8 MHz frequency channel[3] and to avoid interference requires large geographic separation between transmitters that operate on the same frequency. Because the area that can be served by a single TV transmitter is relatively small, this means that coverage of an entire region or country requires multiple transmitters, each of which must operate on a different frequency channel unless they are far enough apart to avoid interference. In practice, an analogue TV station providing national coverage may require as many as 11 frequency channels, a total bandwidth of 88 MHz.

2.2 Digital Multiplexing

Digital TV enables multiple TV stations to be carried on a single frequency channel using a process called **multiplexing** – a single digital TV frequency channel is therefore commonly referred to as a **multiplex**. Digital TV is also less prone to interference, meaning that the geographic separation required between transmitters operating on the same frequency is less than for analogue. If the same programme content is being delivered, transmitters serving adjacent or overlapping geographic areas can operate on the same frequency- a configuration referred to as a **single frequency network** or **SFN**. Regional networks transmitting different content must still use different frequencies to avoid interfering with one another (i.e. operate as **multi frequency networks** or **MFNs**), but the number of frequencies required to cover the entire country is considerably fewer than for analogue. Typically 5 frequencies would be required for national coverage with an MFN configuration, less than half the number required for analogue.

The number of TV stations that can be accommodated on a single multiplex depends on a number of factors, including:

- The technology variant deployed
- The network configuration (e.g. a dense network of lower power transmitters will stations per multiplex for a given level of coverage than a sparse network of higher power transmitters)
- The required picture quality (e.g. whether standard or high definition)

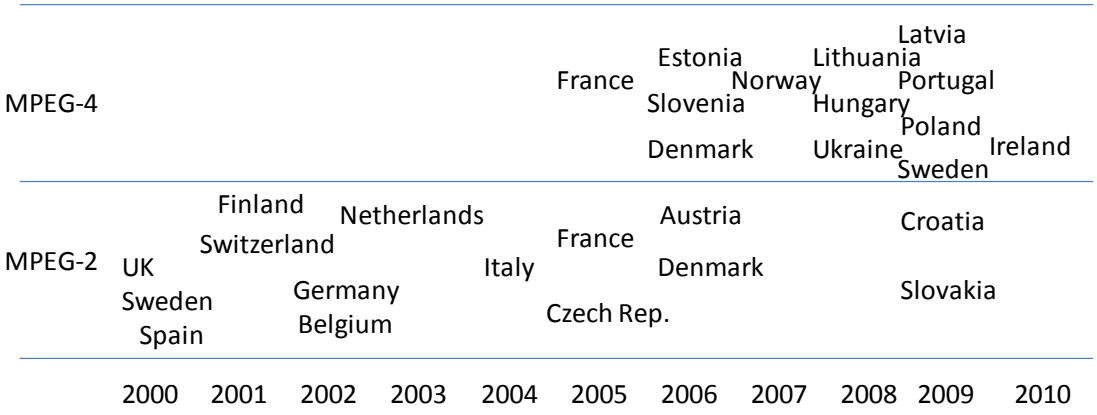
When digital TV was first developed in the 1990s the technology was sufficient to deliver typically 4 – 5 standard definition (SD) TV stations per multiplex. The technology has since improved and it is now possible to accommodate up to 20 SD stations or 3-4 high definition (HD) stations per multiplex, if all the viewers are

[3] Analogue TV channels can by 6,,7, or 8 MHz depending on technology used and regional channel plans

equipped with the latest receiver devices. The two principal developments that have led to this improvement have been adoption of **MPEG4** compression, which provides an approximate doubling of capacity relative to the original MPEG2 format and, most recently, the launch of the **DVBT-2** standard which typically provides a further 50% improvement.

Most of the countries that have adopted DVB-T since 2006 have deployed MPEG-4 and some of those that originally adopted the MPEG-2 standard are progressively upgrading their networks, typically upgrading a limited number of multiplexes initially to allow continued operation of legacy MPEG-2 receivers. The UK is the first country to deploy DVB-T2, to enable launch of a terrestrial HDTV service. Trials are also underway or planned in Austria, Finland, Germany, Italy, Norway, Spain and Sweden. In Serbia, which is planning to launch digital TV in 2010, the Minister of Information Technology and Communications has indicated that DVBT-2 will be deployed[4].

Figure 1 MPEG-2 and MPEG 4 deployment in Europe (source: www.digitag.org)



A more detailed discussion of the parameters that determine how efficiently digital TV can use the available spectrum is presented in the annex to this briefing note.

2.3 Implications for Radio Spectrum

The implications of digital switchover for the radio spectrum required for TV is dramatic. Providing full national coverage for just 5 analogue TV stations would require all of the currently available frequencies, which is ***over 400 MHz*** of spectrum. Delivering this same content over a digital network would in theory require only a single frequency channel for an SFN and no more than six frequency channels for an MFN (48 MHz).

In practice, this reduction in demand for spectrum will be partially offset by the demand for additional TV stations (to enable terrestrial networks to compete with

[4] Source: DVB project web site (www.dvb.org)

satellite and cable offerings), enhanced services such as HD or interactive TV and demand for localised content which constrains the scope for deploying national SFNs. Nevertheless, by deploying the latest digital transmission technology and optimising the transmission network, there will still be a substantial reduction in the number of frequencies required compared to today's analogue TV services.

2.4 The Case for Spectrum Release

The reduction in required spectrum for digital TV broadcasting is often referred to as the **Digital Dividend**. The wide area coverage that makes the digital dividend spectrum attractive for TV also makes it particularly attractive for enhancing coverage of mobile and wireless broadband services. Demand for the latter is growing rapidly around the world and particularly in developing countries where the availability of fixed broadband services is often limited.

To illustrate the potential value of this spectrum for enhancing mobile broadband coverage, the Vietnamese operator EVN Telecom was reported to have launched its 3G mobile network in 2009 with 2,500 base stations, providing coverage to 46% of the population[5]. Our analysis of population distribution in Vietnam suggests that this coverage would extend to less than 10% of the geographic area of the country.

Extending coverage to 99% of the population would require up to 80% geographic coverage, equivalent to an additional 230,000 sq km. The coverage area from a base station operating in the TV band will be up to three times that of an existing 3G site and for reasonable indoor rural coverage would be approximately 90 sq km, compared to 30 sq km in the existing 3G mobile band. Hence achieving this coverage in the existing band would require approximately 7,700 additional base stations, whereas using the digital dividend spectrum would reduce this number to an additional 2,600, significantly reducing costs and speeding up the network rollout.

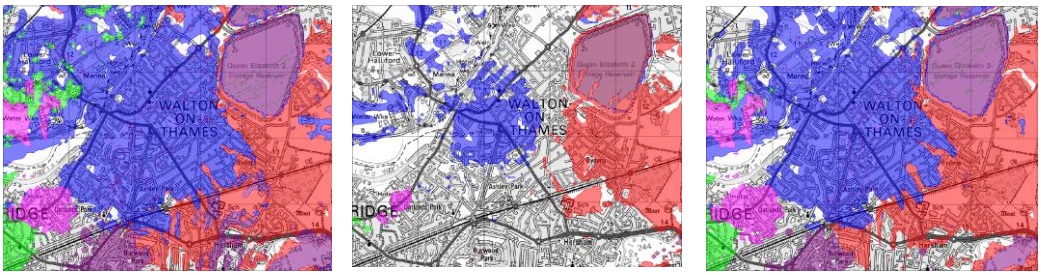
Access to a lower frequency band also provides significant benefits in urban and suburban areas, particularly for indoor coverage as the example shown in figure 2 below, based on the UK, illustrates. The colours represent the indoor or outdoor coverage available from adjacent network base stations.

Whilst similar benefits could be realised by using the existing 900 MHz cellular band, this spectrum is heavily used for GSM voice services, and will continue to be required for many years. It will also not be sufficient to accommodate the massive growth that is projected for mobile broadband services. For example, Nokia Siemens Networks recently forecast an 800% rise in the volume of data transmitted over mobile

[5] Source: Total Telecom / Dow Jones Newswires

networks over the next four years[6] and Cisco projected annual compound growth in mobile data traffic of 129% to 2013[7] .

Figure 2 Comparison of indoor and outdoor coverage in different frequency bands (source: Aegis)



Outdoor coverage (2100 MHz) Indoor coverage (2100 MHz) Indoor coverage (900 MHz)

2.5 Parameters that determine digital TV spectrum efficiency

2.5.1 Digital Compression

Probably the single most important benefit of digital TV transmission is the opportunity for data compression. Without compression, a digitised version of a standard definition colour TV picture would involve a bit rate in excess of 200 Mbps, requiring more bandwidth than the analogue version, however by using an efficient digital coding algorithm the bit rate can be reduced to 5 Mbps or less, a 40-fold reduction that enables 5 or more digital TV stations to be accommodated in the bandwidth of a single analogue frequency channel.

The compression technology used by all current digital TV systems is based on the MPEG-2 set of standards for "the generic coding of moving pictures and associated audio information", which can be tailored to the specific requirements of particular users. Digital compression technology has been further enhanced by the development of the MPEG-4 standard, first released in 1998 and still evolving. In particular, MPEG-4 includes “Advanced Video Coding” (AVC, also standardised as ITU-T H.26, which offers a further reduction of 50% or more in the bandwidth required per TV station.

2.5.2 DVB-T and Multiplexing of TV Stations

Within Europe, digital TV has been standardised as part of the DVB[8] project. The terrestrial standard, DVB-T, is one of a family of standards that includes DVB-C for cable and DVB-S for satellite. MPEG compression is an integral part of all the DVB standards.

[6] Nokia Siemens “Unite” Magazine, issue 5 (February 2009)

[7] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, January 29, 2009

[8] Digital Video Broadcasting

A key concept of the DVB standards is that of the 'multiplex', in which a number of video, audio and data streams are combined into a single transport stream that fits within an existing (analogue) TV frequency channel. The details of this combination can be dynamic, with space on the multiplex being re-assigned, for example, at different times of the day or in real time, a process called **statistical multiplexing**. With statistical multiplexing, it is assumed that peaks of bit rate are unlikely to occur simultaneously across several channels, and each can therefore be allocated spare capacity on the multiplex as required. This results in a considerable saving compared to the case where each channel requires a ring-fenced amount of bit-rate sufficient to cope with occasional peaks.

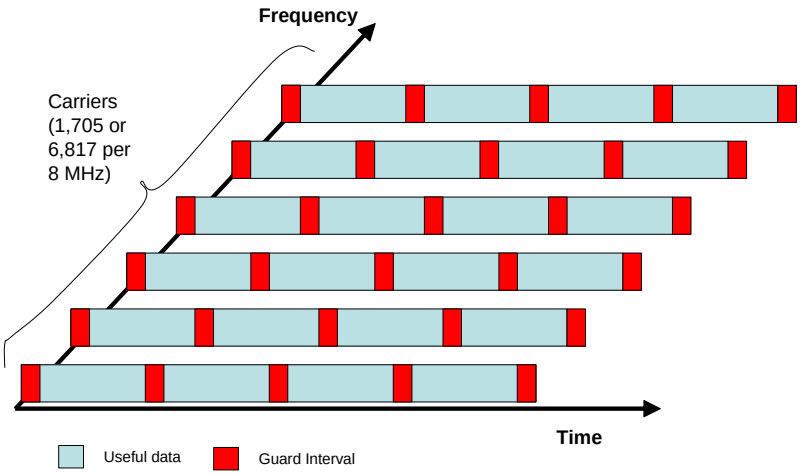
Established multiplexes using MPEG-2 transmission typically carry 4 – 6 standard definition TV stations; however more recent deployments using MPEG-4 have enabled up to three times as many standard definition stations, or several high definition channels, to be carried on each multiplex

2.5.3 Modulation and Coding

DVB-T uses a technique called Coded Orthogonal Frequency Division Modulation (COFDM), in which the data is spread across a large number of individual frequencies (either 1705 or 6817, referred to as '2k' or '8k' modes) that all fit within an existing analogue frequency channel (8 MHz at UHF, 7 MHz at VHF). COFDM is particularly resilient to co-channel interference, which is often responsible for "ghosting" effects on analogue TV reception. This improves reception in mountainous or built-up areas where there are a lot of signal reflections and also means that transmitters serving adjacent or overlapping areas and transmitting the same content can use the same frequency without interfering with one another, a concept referred to as "single frequency network" (SFN).

To realise these benefits, it is necessary to incorporate "guard intervals" between transmitted bursts of data, so that time-delayed signals (e.g. due to multipath reflections or from other transmitters in an SFN) do not cause interference. The guard interval is specified as a fraction of the total data transmitted and values are typically 1/32, 1/16, 1/8 or 1/4. Longer guard intervals reduce the data that can be carried in each channel but allow larger area SFNs to be deployed. The configuration of a DVB-T multiplex in the time and frequency domain can therefore be illustrated as follows:

Figure 3 DVB-T Signal in time and frequency domains



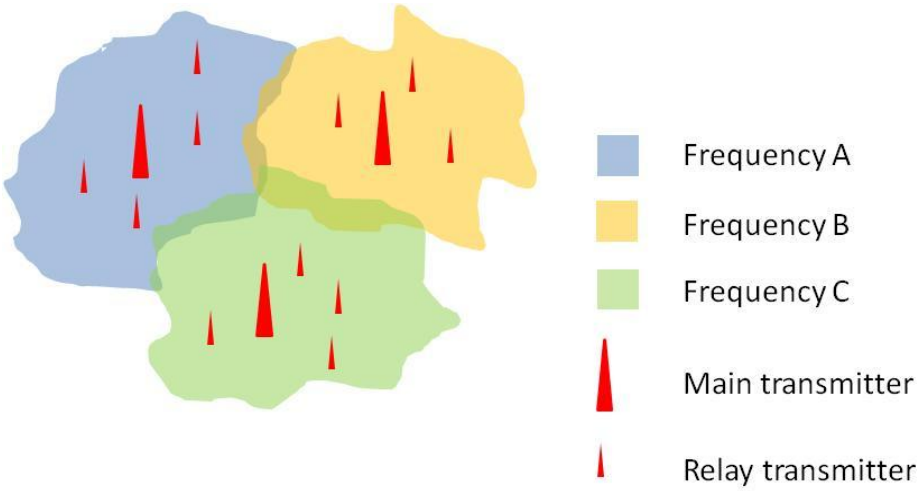
The COFDM carriers can be modulated using QPSK, 16-QAM or 64-QAM, allowing a broadcaster to make a trade-off between overall data rate and signal robustness (i.e. power requirement or coverage area). A range of values are also permitted for the coding rate, between $^{1}/_{2}$ and $^{7}/_{8}$. This figure represents the amount of useful data capacity remaining after error correction codes have been added, so that ½ rate represents the most robustly coded signal.

2.5.4 Impact of Network Configuration

Higher level modulation schemes like 64QAM are less robust to interference but can carry more stations per multiplex. Interference is more likely to arise in networks that deploy a small number of very high power transmitters to meet coverage objectives, than in denser networks of lower power transmitters, hence denser transmission networks are likely to provide higher capacity per multiplex, and hence require less spectrum, than low density networks.

Denser networks of lower power transmitters also have the advantage that a smaller geographic separation is required between co-channel transmitters, meaning that fewer frequencies are required per multiplex. This is particularly important if indoor portable or mobile reception is required, as this would require a low density network to deploy very high transmitter powers and use a larger number of frequencies per multiplex to achieve national coverage. A better solution to providing portable and mobile coverage would therefore be to deploy a denser network of transmitters, perhaps using existing cellular transmitter towers to relay TV transmissions from existing main TV transmitters. The relay transmitters could operate on the same frequency as the nearest main transmitter, effectively creating a localised SFN in the area served by the existing transmitter.

Figure 4 Deploying local SFNs to enhance reception by portable and mobile receivers



There are disadvantages to the use of dense, low-power networks, the most obvious of which are the capital cost and the time required to roll out a new network. Furthermore, the use of directional, rooftop, receive aerials is common in many countries and it may be felt undesirable to require a large number of consumers to replace or re-orient such systems. However, the cost issue could be resolved to a large extent by utilising mobile base station towers as TV relay stations and the higher signal level that would result would largely negate the need for directional rooftop aerials.

2.5.5 Standard Definition vs. High Definition

Standard definition (SD) digital TV provides the same TV picture resolution as analogue (PAL) technology, equivalent to 704 x 480 pixels. Depending on the standard adopted, high definition (HD) TV increases this resolution to either 1280 x 720 or 1920 x 1080 pixels. HD transmission increases the bandwidth requirement by a factor of between approximately 2.5 and 4 depending on the standard adopted. Terrestrial HDTV has so far been largely limited to North America and Japan, but some European countries (such as the UK) are in the process of launching HD over their DVB-T networks, using MPEG4 and/or DVBT-2 (see below) to provide the necessary additional capacity. In general, HD transmission over terrestrial networks is limited to one station for each of the major broadcasters, who typically transmit several other stations in standard definition.

2.5.6 DVB-T2

This recently-adopted (summer 2008) upgrade to the DVB-T standard offers very significant capacity improvements, as well as other benefits. By using improved modulation and coding schemes, DVBT-2 increases the data capacity of a single 8 MHz frequency channel by as much as 50%, can be received by existing domestic DVB-T antenna systems and will co-exist readily with existing DVB-T transmissions.

By combining DVB-T2 and MPEG 4 compression technology, the typical capacity of a DVB-T multiplex can be increased fourfold compared to the earliest DVB-T implementations on which many countries' current DTT frequency plans are based.

Products and services using DVB-T2 are intended to be available commercially from 2010 and a typical scenario could be the launch of high definition TV services over DVB-T2 on new frequency allotments alongside existing standard definition TV services using DVB-T, after analogue broadcasts end.

2.5.7 Summary

Since the launch of the first digital TV services, modulation, coding and compression technology has evolved sufficiently to provide four times the capacity per multiplex, creating scope for further substantial savings in the spectrum required to carry digital TV. This is illustrated in the following table, which shows the amount of radio spectrum bandwidth required per standard definition TV station for various implementations of analogue and digital TV:

Table 1: Estimated spectrum requirement for various terrestrial TV technologies

Technology	Frequencies required for national coverage	Stations per 8 MHz multiplex	Equivalent bandwidth per TV station
Analogue	11	1	88
DVB-T/MPEG2	5	4	10
DVB-T/MPEG4	5	8	5
DVBT-2/MPEG4	5	16	2.5

3 CURRENT SITUATION IN EUROPEAN COUNTRIES AND THE USA

3.1 Introduction

In the USA and many parts of Europe, the transition to digital terrestrial TV delivery has either been completed, or is at an advanced stage. The experience in these regions provides a valuable source of evidence of the practical requirements for digital television spectrum, as a very wide range of technology options, business models, public service provision and regionalisation are covered.

The examples in this section of the report fall into four broad categories:

Countries such as France and the UK, where the transmitter network structure has remained essentially unchanged with the transition to digital. These countries typically have a high level of dependence on terrestrial reception, and a key driver in the transition to digital is a requirement to minimise disruption and expense to viewers. The use of the existing transmitter sites generally implies that SFNs are not widely used, and that reception via rooftop aerials is assumed.

Countries such as the Netherlands and Spain, where significant changes have been made to the transmitter network. In the case of the Netherlands, this reflects the low dependence on terrestrial delivery – as a consequence, the new DTT service is targeting mobile and portable reception, with a consequent need for a denser transmitter network. In the case of Spain, the driver was a requirement to use wide area SFNs for reasons of spectrum availability, which in turn implied that a denser transmitter network was required.

The USA is an example of a territory in which there has been no central planning to ensure a uniform pattern of television coverage. The development of ‘networks’ has been piecemeal, and coverage tends to be limited to areas with a population sufficient to provide an appropriate return on expenditure. Coupled with the size of the country, this coverage pattern tends to allow a larger number of channels to be used in a given area, as there may be no requirement to provide a contiguous service in adjacent areas.

Finally, Greece is an example of a situation in which, while central planning is undertaken, there is a large degree of unregulated spectrum use, with consequent interference problems.

Aside from these broad features of the network structure, there are also a wide range of engineering and service options available. The earliest DTT services were constrained to use MPEG-2, which limits the number of programmes that may be carried on a given multiplex to between 4 and 9, depending on the minimum quality that can be tolerated, and the trade-offs made between coverage reliability and multiplex capacity in the choice of modulation and code rate[9]. More recent services

[9] This trade-off is not available in the ATSC system, where these parameters are fixed.

have launched with MPEG-4 coding, and the DVB-T2 standard offers significant capacity gains to networks able to ignore legacy issues. SFNs may be used where variation of programme content is not required within a given area.

Finally, some broadcasters are offering largely HDTV content, while others concentrate on maximising viewer choice by providing the maximum number of SD channels. This is an area in which viewer expectations and commercial and political imperatives are evolving rapidly, but which will have a significant impact on future spectrum demand by DTT.

The table below summarises some salient features of DTT deployment in the countries studied.

Table 2: Key parameters of national Digital TV Systems

	UK	France	NL	Spain	Denmark	Greece	USA
No of national layers post-DSO (UHF)	6	7 (will expand to 13)	5	8	6	12	n/a
TV at VHF?	no	no	no	no	no	Local use to augment UHF	yes
Mobile TV at UHF?	No	2 (of the 13)	1 (of the 5)	1	?	no	no
Modulation	64-QAM	64-QAM	64-QAM	64-QAM	64-QAM	16-QAM	ATSC
Large-area SFN use?	no	no	yes	yes	no	yes	no
Coding	MPEG-2 MPEG-4[1]	MPEG-2[1] MPEG-4	MPEG-2	MPEG-2	MPEG-4	MPEG-2	MPEG-2

[1] one (HDTV) multiplex only, [2]Public Service multiplexes only,

3.2 United Kingdom

A detailed description is given of the background to digital switchover in the UK, as it illustrates issues that are typical of many European countries.

3.2.1 Historical background

The original (1936 onwards) TV services in the UK were provided using VHF frequencies, and a standard based on 405 scanning lines. By the late 1950s this standard was showing its age, and the decision was taken to move to the common European standard of 625 lines and UHF transmission. The two existing 405-line services were duplicated at UHF[10], and two new services added. As it was mandated that all the new services would share transmitter sites, this created a simple and uniform pattern of distribution, in which some 99% of the population was eventually covered and only a single UHF aerial was required to receive all services. Although "regionality" was allowed for, the main planning goal was to achieve uniform national coverage of the four channels.

The transmission network was based around 50 high-power 'main' stations, fed with video by landline from studios or distribution centres, and serving areas with as little overlap as possible. The main station areas are indicated in Figure 5 below. Within the nominal service area of each main station, a large number of coverage deficiencies would typically remain, caused by the high terrain diffraction losses experienced at UHF frequencies. These deficiencies were filled by relay stations of different sizes (ranging from 10kW sites with 50m masts, to 1W transmitters with simple aerials mounted on telegraph poles), each of which *translated* the four incoming channels to different frequencies and re-transmitted them at appropriate power. A total of around 1000 such relays were eventually constructed.

An important point to understand in the context of the UK digital switchover is the way in which frequencies were allocated to the transmitters in the analogue UK network. Two major constraints existed[11]; firstly, it was desirable to limit the bandwidth required by transmit or receive aerials to around 100 MHz (to maximise efficiency) and secondly it was not possible to use adjacent channels (the so-called '*taboo'* channels) to transmit services from the same transmitter, as this would cause mutual interference between analogue signals.

Consequently, standard groups of channels were used at UK transmitters, as illustrated in Figure 6 below.

[10] The VHF services were switched off in 1984, and the bands released for other use

[11] There are other constraints relating to channels which cannot be used in the same area, but these are not discussed here.

Figure 5 UK main & relay station transmitters

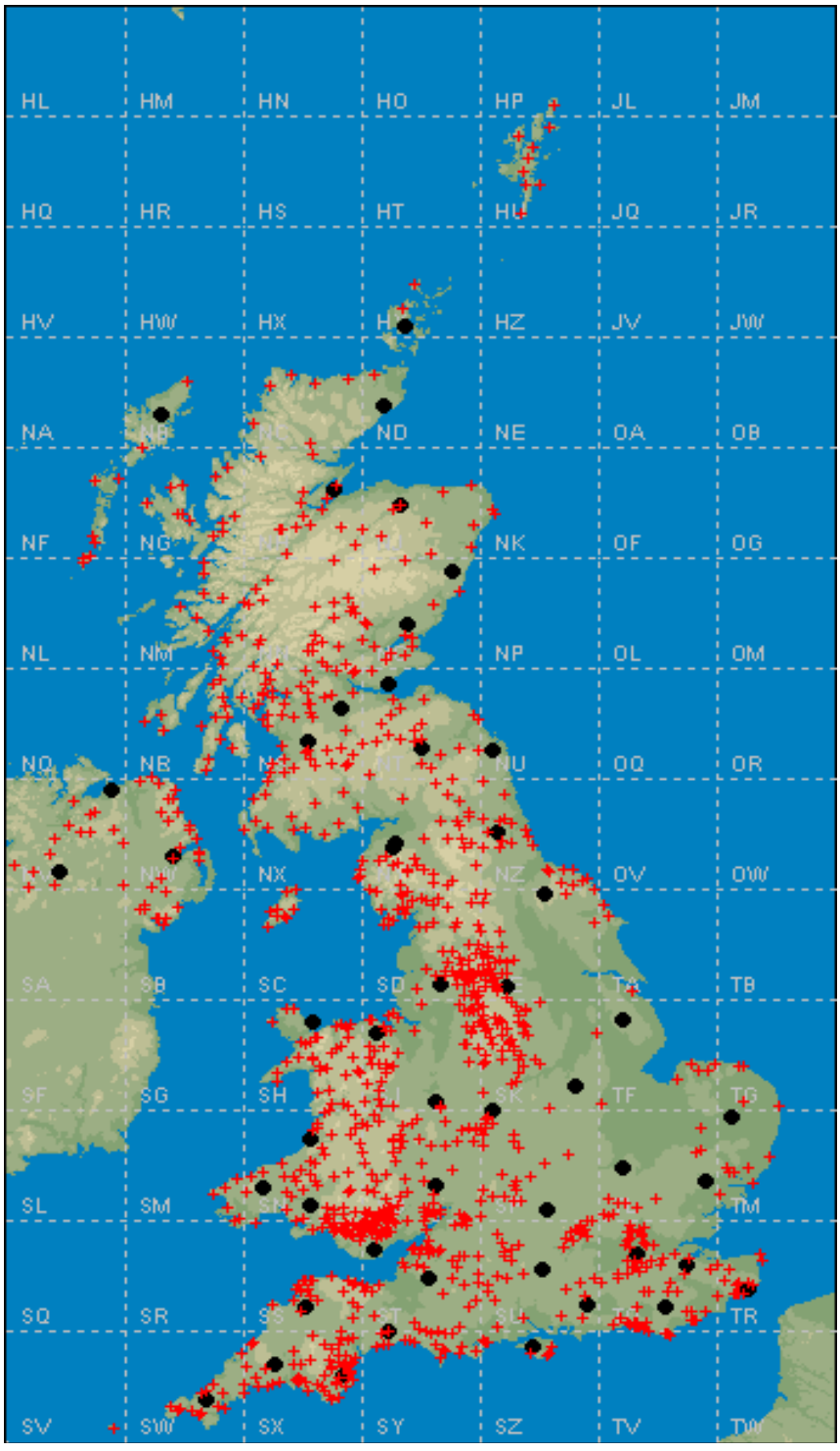
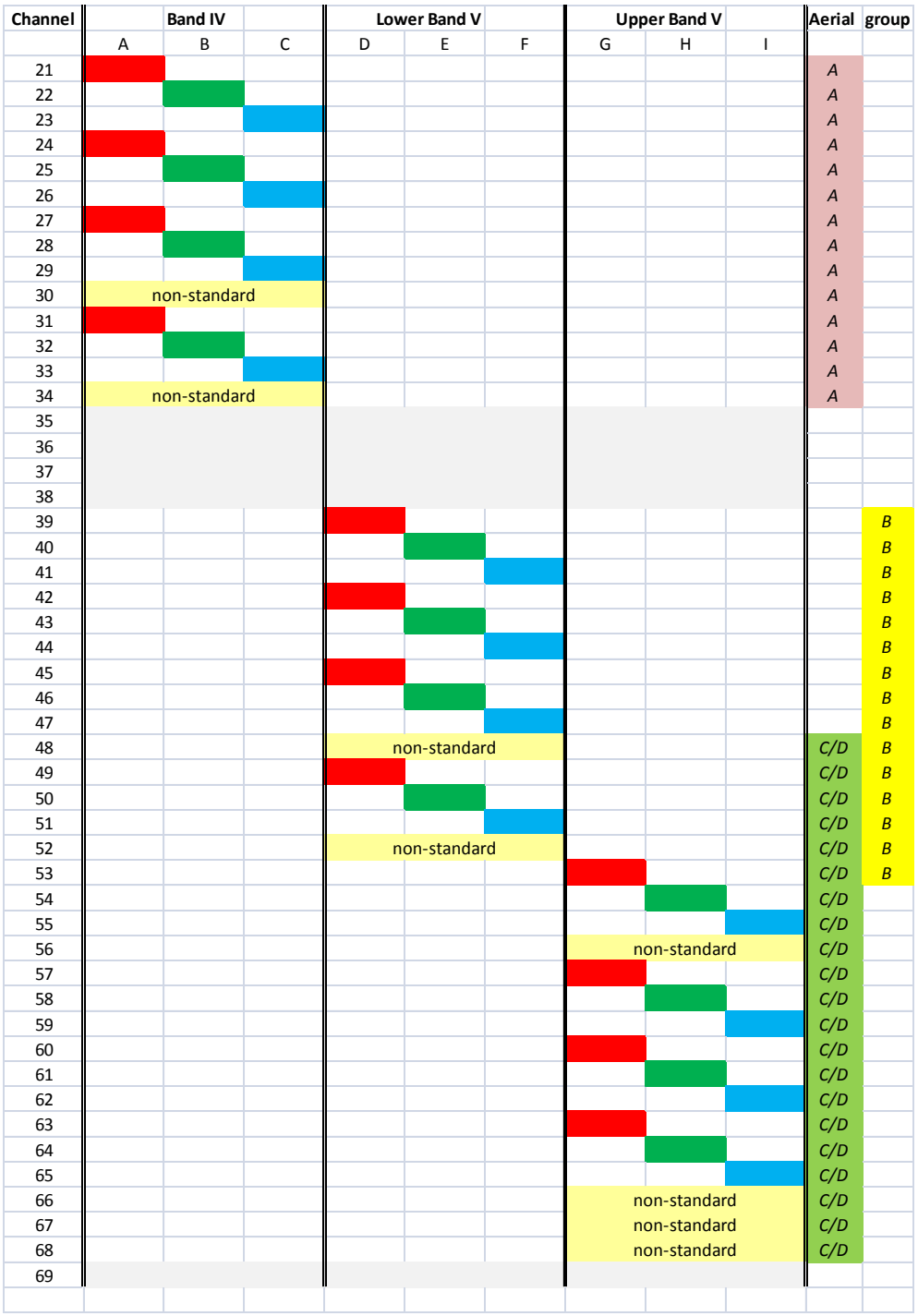


Figure 6: UK television frequency groups.



Thus, if a transmitter uses channel 40, it will also be found to radiate on channels 43, 46 and 50. This system breaks down in some areas, particularly around the coast where incoming or outgoing interference renders the use of some channels in a standard group impossible. In this case, a non-standard grouping will be necessary, probably making use of the eight channels that do not fit in the standard groups. An example of this is at Dover, where channels 50, 53, 56 and 66 are used.

The only significant change to this frequency planning scheme, in the analogue era, was made with the introduction of a new TV service, 'Channel Five' in 1997. This channel initially made use of channels 35 and 37, which had not formed part of the original UHF broadcast band (falling in the gap between 'Band IV' and 'Band V'). These frequencies allowed a coverage of some 65% of the population, from 33 transmitters, later extended to a total of 54 main and relay transmitters. As the transmitter network was sparse, often of low power and generally used channels outside the nominal aerial group for the area, many reception problems were reported. Similar problems have been encountered with the initial digital TV network.

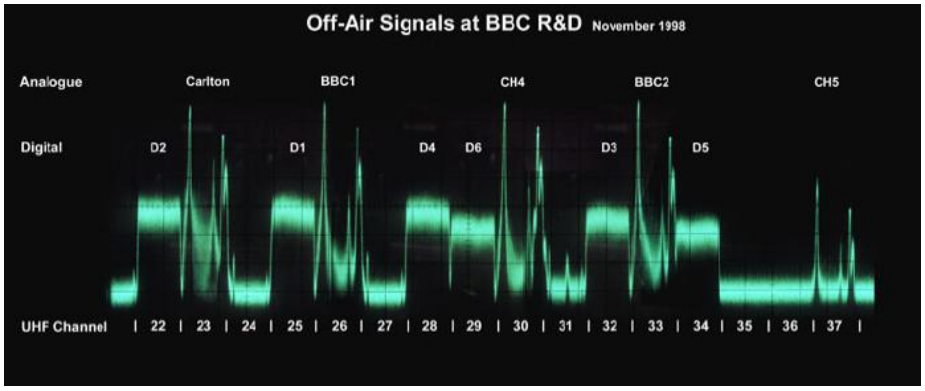
Channel 69

It should be noted that channel 69 has never been used for TV broadcasting in the UK, but is currently reserved for use by low-powered wireless microphones (licensed and licence-free)

3.2.2 DTT - the interim network

Digital terrestrial TV, using the DVB-T standard was introduced in the UK in 1998, in parallel with the existing analogue network. The DTT signal is significantly more robust than the analogue signal, and requires lower transmitter power. As a consequence, it was possible to interleave the six digital multiplexes (each occupying one 8 MHz channel) between the analogue services from each transmitter, using the '*taboo*' channels, as shown in the spectral plot in Figure 7, of the main transmitter for the London area.

Figure 7: Showing interleaved analogue and DTT transmissions (source BBC).



Despite the robust digital signal, the scarcity of available spectrum and the need to avoid interference to analogue services meant that coverage was rather sparse, with only 80 Transmitters (50 main stations and 30 of the higher-power relays) brought into use. The population coverage varied from multiplex to multiplex, but was between 66% and 82%, with only 57% of the population able to receive all six multiplexes. This 'core' coverage increased to 66% as the network was refined through changes to powers, antenna patterns and frequencies.

The service launched using 64-QAM modulation, which offered the greatest capacity (24 Mbit/s per multiplex). This mode, however, is also the most demanding in terms

of the minimum signal level, and tolerance to interference. The initial pay-TV service (branded 'ON-digital' and later 'ITV digital') failed commercially, and in the light of this the opportunity was taken to conduct field trials of different modulation modes. When the new free-to-air service (branded as 'Freeview') was launched, the decision was taken to move four of the six multiplexes to the 16-QAM modulation scheme, trading lower capacity (18 Mbit/s per multiplex) for more robust reception. The eventual core coverage of the interim DTT network was around 73%.

3.2.3 DSO and spectrum release

The coverage of the interim DTT network was unavoidably limited by the need to continue simulcasting the existing analogue networks. It would only be possible to attain full coverage when the spectrum used for the analogue transmissions could be freed for use by DTT services. At this 'Digital switchover' (DSO) it would become possible not only to increase the power transmitted by the DTT services, but also to bring all the 1,000 relay stations into operation, instead of the 30 used in the interim network. These changes would also allow all multiplexes to use the higher-capacity 64-QAM modulation system.

There was considerable debate as to the eventual form of the UK DTT network, and, in the early stages, these were proposals for the use of single frequency networks (SFN). However, this was not pursued for a number of reasons. Perhaps most importantly, the use of an SFN would not allow for regional content within the networks. Secondly, any SFN requires a certain maximum spacing between the transmitters forming the network. In the case of DVB-T, this maximum distance is in the order of 67km. This is not sufficient to accommodate some of the transmitter spacings found in the UK, for example, along the South Coast. Thirdly, the use of such wide-area SFNs would require sacrificing overall channel bit-rate to provide a larger guard-interval. Fourthly, it is by no means certain that a channel could be found that would be available across the UK, given the constraints of international interference. Finally, the use of an SFN would imply that the majority of existing household aerials would be operating out of group, and many would require an upgrade.

The final plan was, therefore, to adopt a multi-frequency network, based on the existing analogue channel allocations. This has the advantage of minimising the number of changes required to international agreements, and also maximises the number of receive aerials that can be re-used.

It was realised at an early stage of DTT planning that the efficiency of digital delivery would allow for a significant release of spectrum - the so-called Digital Dividend. At the point at which the plan was being formulated, however, there was no consensus nationally or internationally, as to what use might be made of such a dividend, or of where the released spectrum should be located.

The final UK DTT service is to consist of six multiplexes with national coverage, three of which will carry public service (PSB) content, with the remainder being purely

commercial (COM). The PSB multiplexes would be carried on all main and relay transmitters, while the COM multiplexes would only be carried at the largest relay sites.

A plan was adopted in which the three PSB multiplexes inherited three of the four existing analogue channel assignments at each transmitter. The legacy of international co-ordination and appropriately grouped receive aerials should ensure that these services will suffer minimal reception problems. The COM multiplexes are to be assigned 'new' channels, as national and international constraints permit.

The use of three out of four channels from each group thus suggests a simple plan for spectrum release in which channels at the top of Band IV are released, and at both top and bottom of Band V are released. This ensures that all planning groups still retain at least three of the original four channels. The plan is illustrated in Figure 8.

At the Regional Radio Conference (RRC-06) it was not necessary to make any explicit reference to spectrum release, as it was judged that, in the absence of any international consensus on spectrum release, to negotiate on the basis that all channels would be used for DTT would result in a plan that would not restrict other possible uses.

Until 2008, therefore, the plan was for the UK to release channels 31 - 40 and 63 - 68 to the market to support new services, or commercial DTT. Although the plan was intended to be technologically neutral, it was expected that the lower released channels might be attractive for fixed or mobile TV services, while the upper channels might be well suited for fixed or mobile broadband provision.

Since the RRC, however, there has been a major drive by many organisations both within the International Telecommunications Union (ITU) and at European level to harmonise spectrum released under the digital dividend. The 2007 ITU World Radio Conference (WRC-07) decided to allocate 790 – 862 MHz (Channels 61-69) to the mobile service on a co-primary basis with broadcasting throughout Europe and Africa by 2015 at the latest. In Europe, CEPT has developed detailed plans to facilitate the introduction of mobile services in this spectrum, on a harmonised but non-mandatory basis.

As a result, it is now proposed to modify the UK plan to allow the release of channels 61 and 62. That this is not a trivial issue can be seen from Figure 9, which shows the locations of transmitter sites using these channels. A significant re-planning exercise will be required to accommodate these displaced services, and, at some sites, it will be necessary to replace transmitting antennas at considerable expense. It may be necessary to make use of some of the lower 'release' spectrum to accommodate these displaced assignments.

Figure 8: Relationship of released spectrum to planning groups

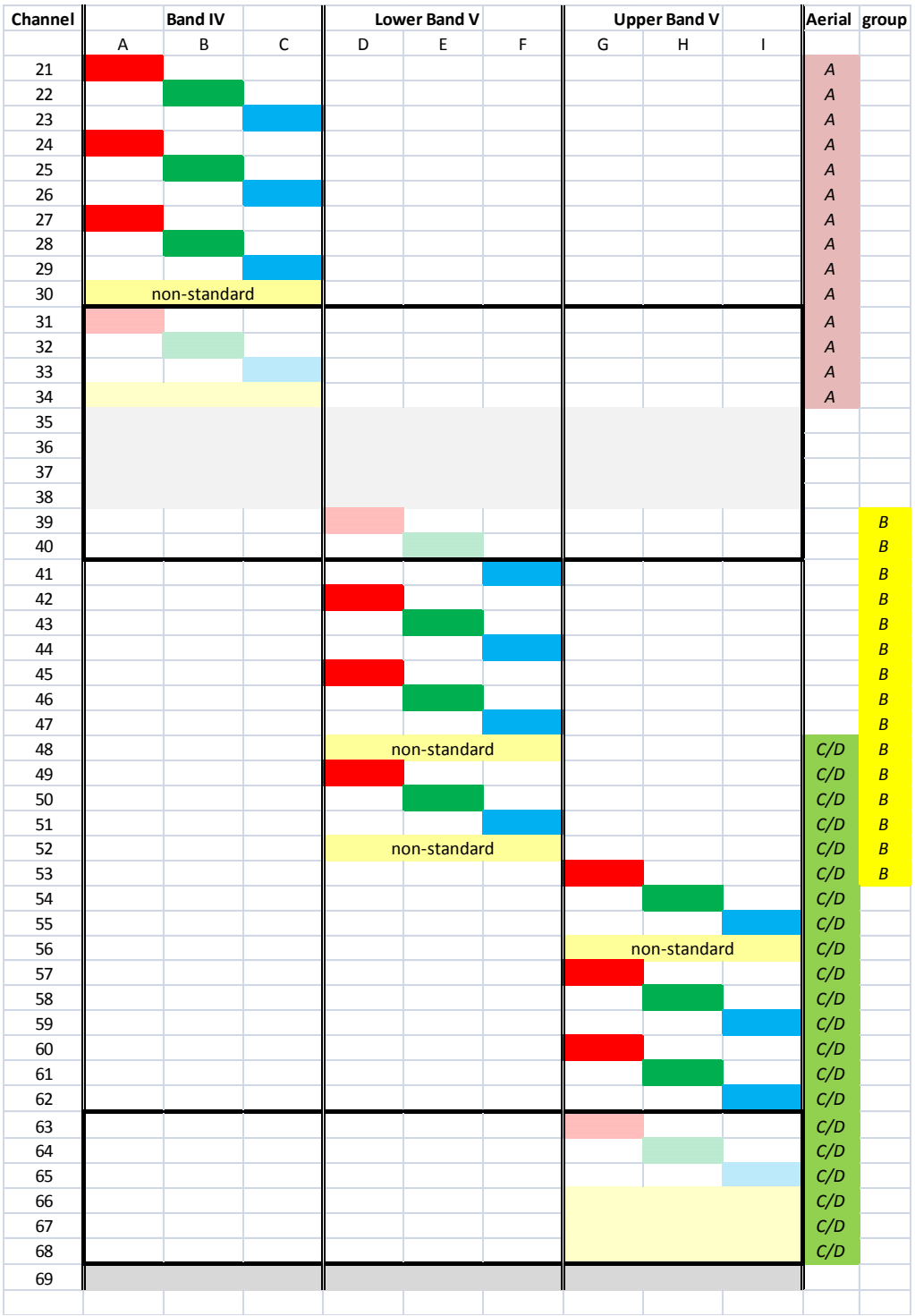
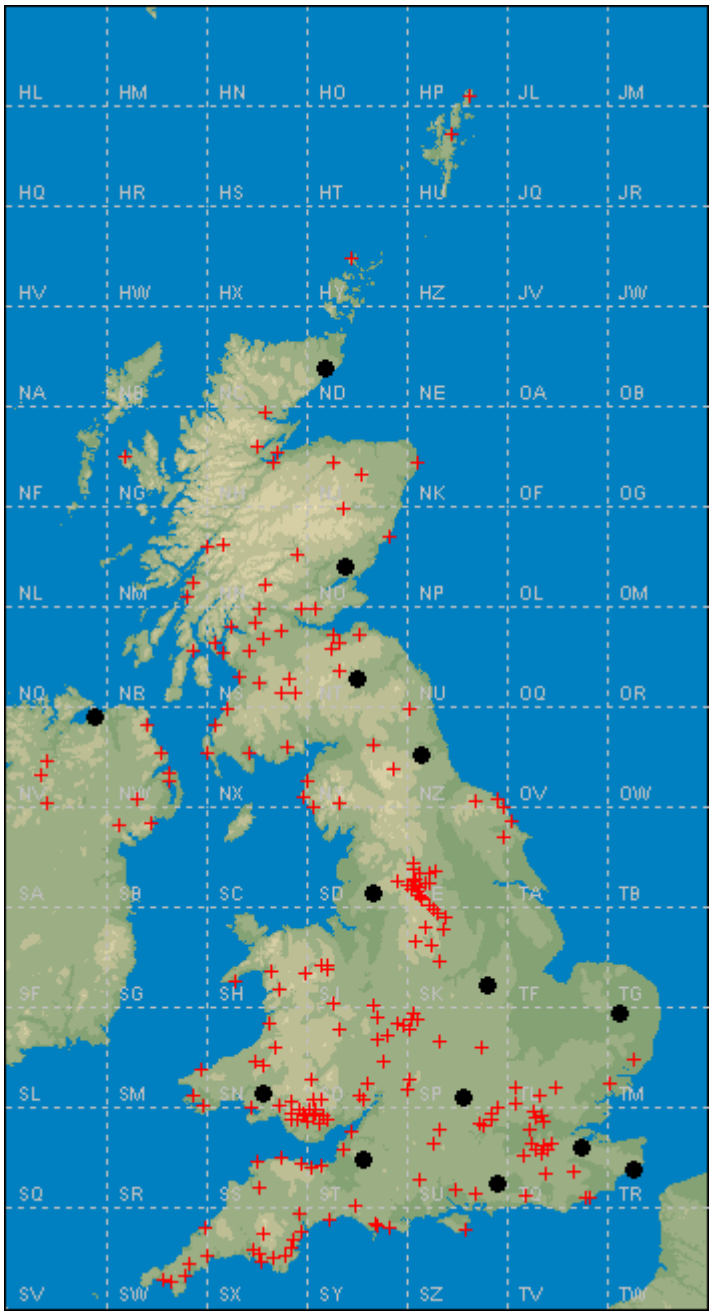
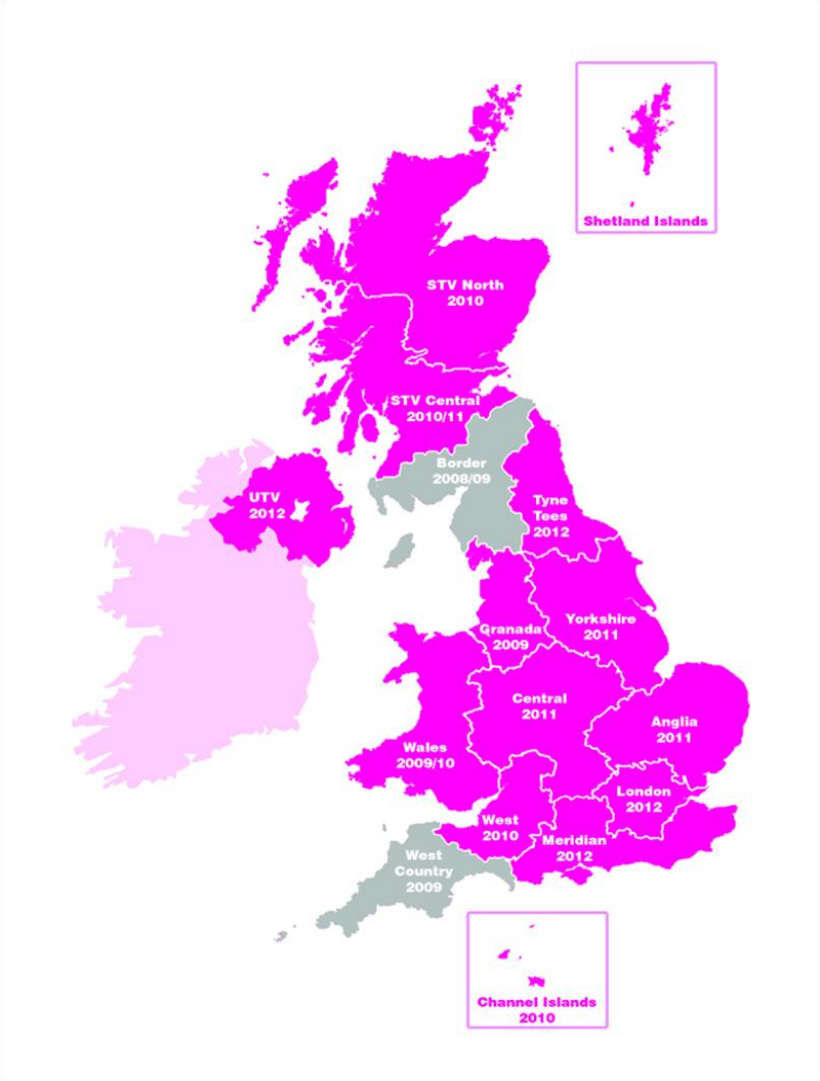


Figure 9: Main & relay sites planned to use ch.61 & 62 post-DSO



The termination of analogue services and the launch of the full-power final DTT network are currently being progressed across the UK on a regional basis. The 'Borders' area of Southern Scotland and Northern England was the first to switch, in 2008, and the process will conclude with switchover in the London area in 2012.

Figure 10: Regional switchover timetable for UK (Source: Ofcom)



3.2.4 HDTV and DVB-T2

There had been a significant amount of lobbying by broadcasters to be allowed to retain some of the Digital Dividend spectrum for the express purpose of providing High Definition (HDTV) services. Ofcom, however, took a robust view that any additional spectrum should be acquired in competition with other users.

Using the current DVB-T / MPEG2 combination it is only feasible to provide a single HDTV programme in an 8 MHz channel. However, a major effort within the DVB consortium, led by the BBC, led to the development of an enhanced standard, DVB-T2 for terrestrial TV. Taken together with the use of MPEG-4 video compression, the use of DVB-T2 makes the carriage of multiple (e.g. 3-4) HDTV services within a single 8 MHz channel possible. It is now intended to take advantage of this technology to launch DTT HDTV services in the UK.

These services will be accommodated in one of the three PSB multiplexes and at the moment of DSO in each region, the existing services will be replaced with DVB-T2/MPEG-4 transmissions. The first such services will be transmitted in the North West of England following the areas DSO in November 2009. It is hoped that consumer equipment for the new standard will be available in early 2010.

It might be noted that the introduction of HDTV on the DTT platform will leave the majority of viewers able to receive only two PSB multiplexes.

3.3 France

The situation in France is, perhaps, the most similar to that in the UK, in that terrestrial delivery is still the most important means of TV distribution. The UHF network is very extensive, and has the same pattern as in the UK, with high power horizontally-polarised main stations and a large number of local, vertically-polarised relays. The UHF network was planned to offer three uniform coverages (TF1, France 2 and the regional France 3), using channel groupings similar to those in the UK, and all using the same transmitter network. It should be noted that Channels 66-69 (830-862 MHz) have never been used for broadcasting in France, but were reserved for military use.

The transmitter network is very extensive, making use of around 100 main stations and over 3000 relay sites to achieve a 99% population coverage. This reflects (or perhaps has driven) the high dependence on terrestrial delivery in France, where it is the primary means of delivery for around 60% of homes.

These services have since been supplemented in the 1980s by ‘Canal Plus’ (an analogue encrypted pay-TV service operating on the VHF frequencies vacated by the old 819-line service) and by France5/Arte and M6 at UHF. The two new UHF networks have somewhat less comprehensive coverage (~85%) than the original three.

3.3.1 Interim DTT network

Free to air services started in March 2005, from 17 transmitter sites, with over 500,000 DTT adapters sold by July and 35% of the population covered. The coverage had grown to 88% of the population by August 2009. The DTT services are marketed as Television Numérique Terrestre (TNT), a similar branding approach to ‘Freeview’ in the UK.

Planning is on the basis of 6 national-coverage multiplexes. Five of these networks (*Reseaux 1-4 and 6*) have been allocated to TNT, but ‘*R5*’ was held back while consultations were carried out by the CSA[12] as to whether this resource should be used to provide mobile TV or HDTV services. The latter option was chosen, and the multiplex is now being used to carry three HD channels (TF1, France 2 and M6), with

[12] Conseil Superieur de l’Audiovisuel

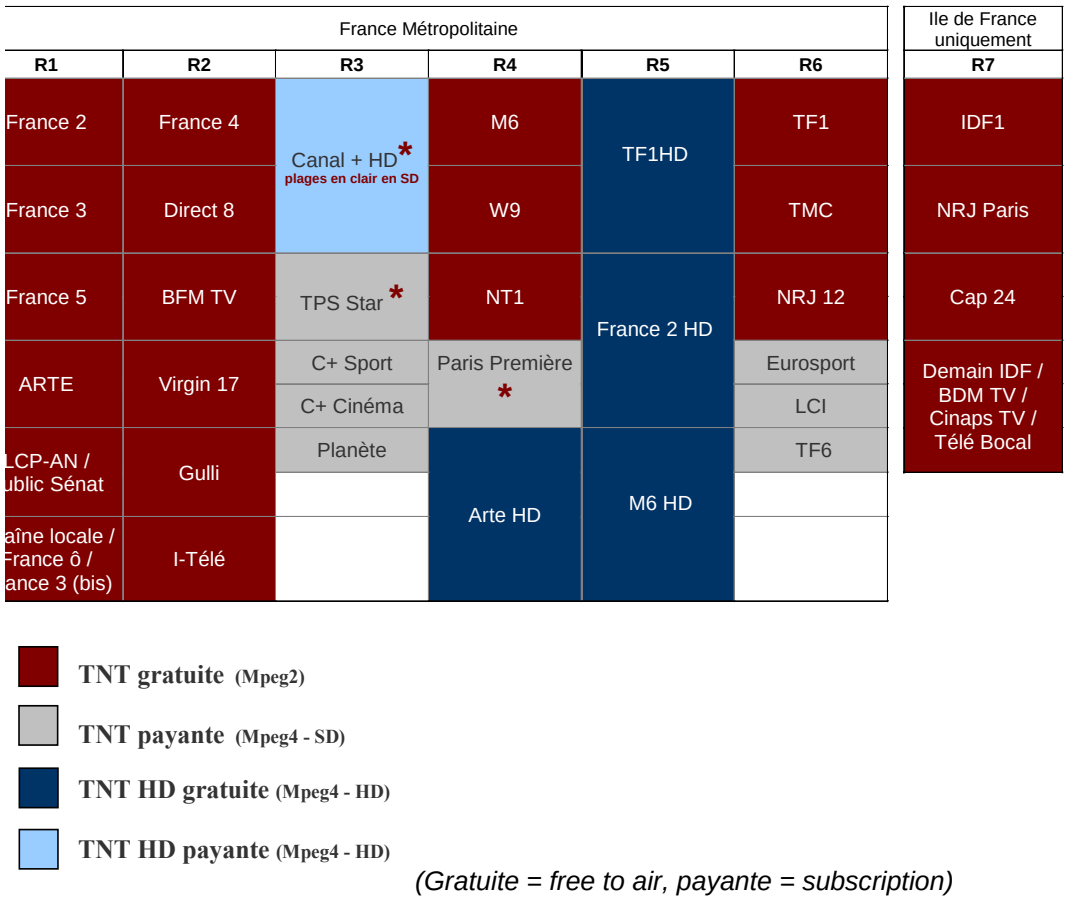
content simulcast from their SD offerings. The coverage on R5 is currently being built up to match the other services.

A further local multiplex, R7, will provide DVB-T in urban areas, starting with the Ile de France (Paris).

In a somewhat unusual move, necessitated by a requirement to roll out public service coverage quickly and at minimum cost, MPEG-4 was mandated in May 2005 by CSA for pay TV and HDTV services, but MPEG-2 can be used for PSB SDTV services.

The TNT platform carries 18 free-to-air services and 11 pay channels, as indicated in the figure below.

Figure 11: TNT multiplexes as at June 2009



As of Q1 2009, 43% of the population relied on DTT and 17% on analogue terrestrial. A free to air satellite service (CanalSat 'TNTSat'), provides an alternative source of the 18 FTA programmes for those (~5%) beyond the final reach of the TNT network.

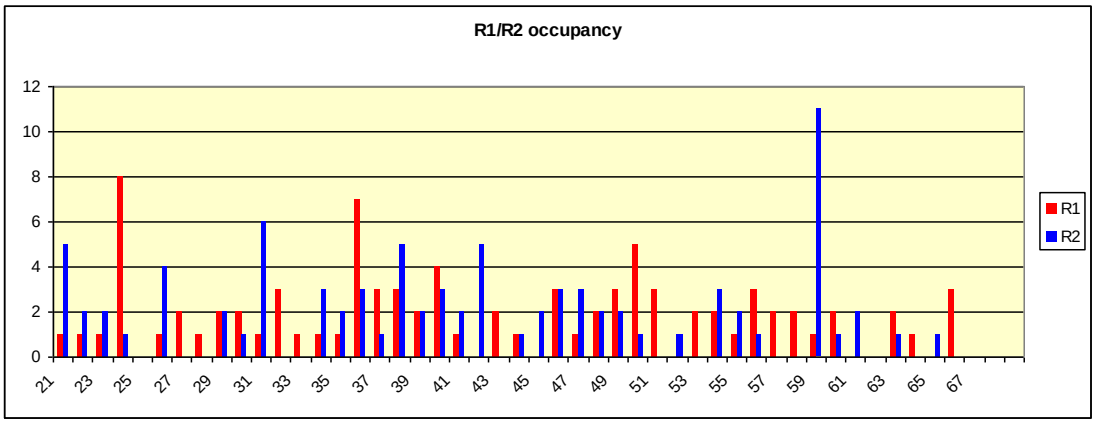
3.3.2 Post-switchover

The legislation "*Television du Futur*" of March 2007, allocated the Digital Dividend' in France. It confirms that the band 790-830 MHz[13] will be released for use by mobile broadband access systems, while the remainder of the Dividend spectrum will be retained for broadcast use. A total of 11 DVB-T multiplexes are envisaged, together with 2 mobile TV (DVB-H) multiplexes.

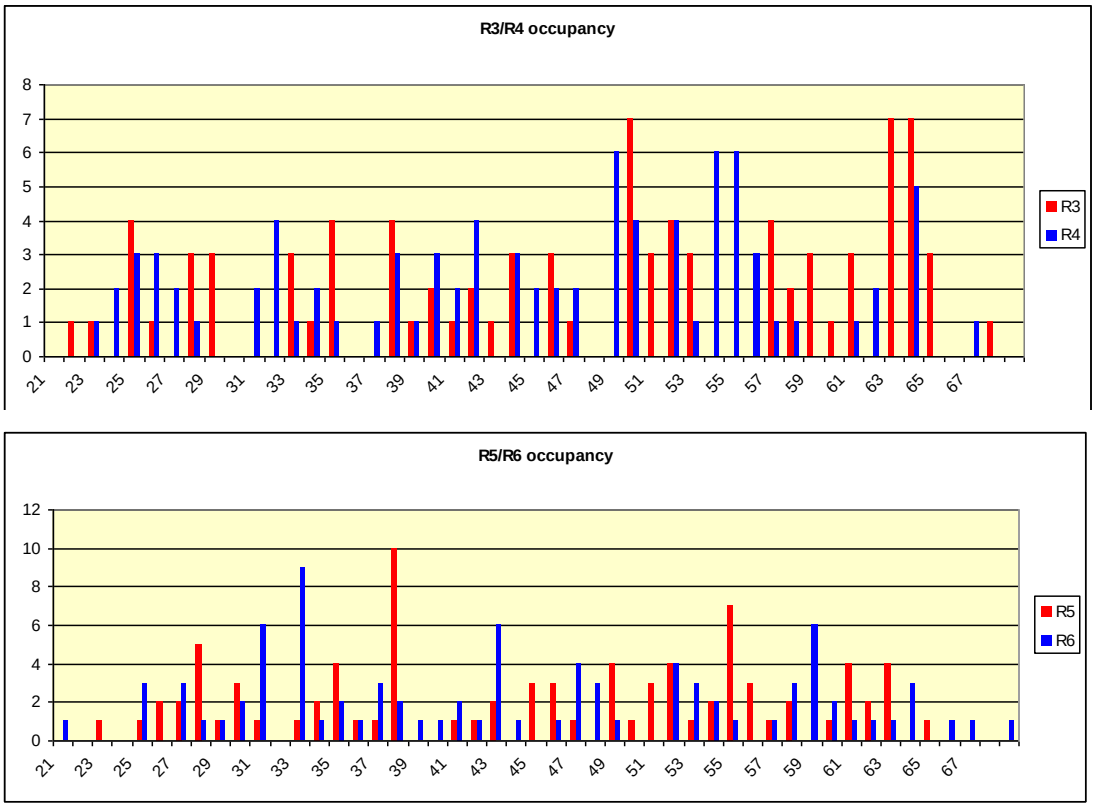
These proposals will require a very substantial re-planning with respect to the original GE-06 allocations. Currently, the entire UHF TV spectrum is supporting 13 coverage layers (three analogue channels with 99% coverage, two analogue channels with ~85% coverage, six DTT multiplexes that should reach 91% coverage prior to DSO, a further local DTT multiplex with a potential 70% coverage and a single (currently unused) DVB-H multiplex). The same number of digital services will therefore need to fit in 40 MHz less spectrum.

The frequency resources obtained at GE-06 did not, explicitly, allow for spectrum release above 790 MHz. The allocation of channels to each multiplex is illustrated in the figures below, and it can be seen that all are distributed fairly evenly across the spectrum.

Figure 12: Channel distribution of requested French assignments



[13] Channels 66-69 (830-862 MHz) were not used for broadcasting in France



The VHF frequencies currently used for the analogue subscription channel, Canal+, will be released starting in 2010, and will then be used for digital radio broadcasting using the T-DMB standard.

Although several trials have taken place, and licences awarded to content providers, the launch of mobile TV services (known as TMP) has been delayed as the parties are unable to agree on a business model or a means of funding the dense transmitter network required.

3.4 Greece

It is probably fair to say that Greece presents a contrasting case to the centrally-planned and carefully regulated broadcast landscape represented by France and the UK. Although the regulator has developed detailed spectrum plans and licensing regimes, the actual use of the spectrum appears to bear little relation to these documents.

3.4.1 Historical background

Regular TV broadcasting started in 1966, and by 1987, the state broadcaster, ERT ran two national channels, and a regional channel in Thessaloniki. The ET1 channel uses primarily VHF frequencies, while the other networks mostly use UHF.

During the 1980s a large number of unlicensed private stations began to appear, often rebroadcasting satellite channels, pirated films or pornography. A licensing

regime for private broadcasters was introduced in 1989, but there is little correspondence between the 'official' spectrum plan and the actual use of the airwaves. In most urban area, the majority of VHF and many UHF channels are fully used, with considerable interference apparent as a result. There appears to be little policing of unauthorised transmissions, which, in any case, may not be illegal.

3.4.2 Interim DTT network

In 2006, ERT launched a pilot DVB-T service, consisting of a single multiplex carrying four services. It is noteworthy that these services are not simulcasts of the existing analogue channels. The DVB-T service is currently available in the larger urban areas and uses MPEG-2 coding.

In July 2009, a new company, DIGEA, was formed to manage the DTT services offered by a consortium of seven existing private broadcasters. This group have published a specification for DVB-T receivers, which mandates the inclusion of both MPEG-2 and MPEG-4 decoders, but only at standard definition. The receivers are required to operate at both VHF and UHF.

The first DIGEA service has been launched in the area surrounding the Gulf of Corinth.

3.4.3 Digital switchover

The transition from analogue to digital TV is scheduled to complete in November 2012 with the closure of the analogue services. During the transition phase, it is planned to deliver seven digital multiplexes from 23 former analogue transmission sites, using some or all of the frequencies previously used for analogue transmission at those sites.

The final frequency plan is required to support six national services, as follows:

- Duplicate existing ERT services (1 MUX)
- New ERT services (1 MUX)
- Shared between ERT and new subscription services (1 MUX)
- Commercial national services (2 MUX)
- Mobile TV using DVB-H (1 MUX)

In addition to these six national multiplexes, sufficient local capacity must also be made available to support the existing local services. The number of such channels varies from region to region, but is as high as 13 in some areas.

The final frequency plan was developed by National Technical University of Athens and provides for 12 multiplexes[14] to be available in each of 11 "broad coverage areas" (ΕΠΨΕs), which have been derived from the original 42 coverage areas that were defined for analogue television.

[14] delivered using an unusual configuration involving two partially-overlapping SFNs carrying the same content within each area, thus requiring 24 frequencies

This plan makes no provision for the release of spectrum for non-broadcast purposes, and is based on the use of DVB-T (16-QAM) and MPEG-2 technology, providing for only 4 TV services per multiplex.

Even with this relatively inefficient technology, there appears to be significantly greater capacity available within this plan than is likely to be required by all existing and envisioned national, regional and local services. It seems likely that the existing plan will be modified substantially prior to DSO, and there is ample opportunity to ensure that spectrum above 790 MHz is released.

It should be noted, however, that channels 67-69 (838-862 MHz) are reserved for military use; this does not, however, seem to preclude their use in some areas by existing analogue TV services, although these are, presumably, unlicensed.

3.5 Spain

3.5.1 Historical background

An early decision was taken to make use of the SFN technique to provide coverage in Spain. It quickly became clear, however, that the intensity of use of channels 21-65 by the analogue TV services made it impossible to find any nationally-available spectrum for such networks. However, channels 66-69 had never been used for broadcasting, having been reserved for studio-transmitter links by radio broadcasters. These links were therefore migrated to other spectrum.

3.5.2 Interim digital services

In a similar fashion to the failure of ONdigital in the UK, the initial pay-TV operator in Spain (Quiero) failed commercially. The DTT service was then re-launched in November 2005.

Seven national multiplexes were licensed, of which 5 were on-air in November 2005. In addition one or two local multiplexes are available in most areas:

- MUX 1 RTVE (regionalised MFN)
- MUX 2 VeoTV (national SFN, ch.66)
- MUX 3 (national SFN, ch.67)
- MUX 4 *Tele 5* (national SFN, ch.68)
- MUX 5 *Antena 3* (national SFN, ch.69)

3.5.3 Digital transition

Analogue switch off is being phased regionally, with the first areas switching in summer 2009.

Following analogue switch off (scheduled for April 2010), eight multiplexes will be available, four licensed to the existing analogue commercial stations, two to the current DTT operators and two to RTVE. HDTV services will be permitted on these

multiplexes, and the government will mandate the inclusion of an MPEG-4 decoder in receivers with larger screens.

RTVE is required to provide a service to 98% of the population, while the commercial multiplexes have a somewhat lower coverage target of 96%.

In July 2009, the government announced that a DVB-H multiplex will be licensed, but no business model has yet been agreed by any potential operators.

In August 2009, the government made legislation to allow the provision of pay-TV services.

As noted earlier the release of the upper portion of 470 – 862 MHz is likely to be difficult due the widespread use of these channels for digital TV in Spain. Spain's reservations about the harmonisation proposal, noted in CEPT Report 22, stated that the release of channels 62 – 69 was the worst of the four release options originally considered for Spain. After switchover new multiplexes will be allocated and Spain indicated that 5 layers will need to be allocated to DVB-T in the channel 61 – 69 range taking into account that 7 multiplexes are already operational. Also all the existing Digital Terrestrial TV layers use some frequencies in the upper part of the spectrum and this includes 4 nationwide SFN multiplex in channels 66, 67, 68 and 69.

However despite these issues Spain has decided to release the 790 – 862 MHz band for mobile services.

Analogue switch-off is scheduled on 3rd April 2010. On the 2nd of June 2009, the Spanish government announced the objective of clearing the 790-862 MHz sub band

A royal decree is in process, establishing that starting in 2015 this sub-band will be available for electronic communication services other than broadcasting, e.g. mobile broadband. The 800 MHz band will be available in Spain as a digital dividend for new applications as of 1st January 2015.

3.6 Denmark

3.6.1 Historical background

The initial TV service in Denmark (now DR1) was provided in the Copenhagen area using frequencies in VHF band I (~60 MHz). During the 1950s and 1960s, this network expanded to cover the entire country, with most of the new transmitters using the higher frequencies of Band III (~200 MHz).

A second terrestrial network was launched in 1988, with a completely different set of transmitter sites, and using frequencies only in the UHF band (470-860 MHz).

A third public service channel, DR2 was launched in 1996 using only satellite and cable. Since then a very limited terrestrial network has been added using a mix of VHF and UHF frequencies to serve a few local areas.

Most households in Denmark therefore had two aerials on the roof, one for the VHF (DR1) network and a second for the UHF (TV2) network. In the south and east of the country, many homes are equipped with further aerials to receive services from Germany or Sweden.

3.6.2 Digital switchover

The new digital services use UHF frequencies only, transmitted from the sites of the existing TV2 network. A total of 7 UHF channels are available at each site, with two assigned to the public service broadcasters (DR and TV2), four granted to a commercial company, Boxer A/S, for the distribution of Pay-TV services and the final channel (in the hitherto military band 61-68) being reserved for future use, though it appears that this will not, now be released. A new organisation, DIGI-TV has been established to operate the PSB multiplexes.

All networks use DVB-T with 64-QAM, but the first PSB multiplex employs MPEG-2 coding while the others use MPEG-4. All networks operate as MFNs[15], allowing a high degree of regionality. Licenses have been issued for 220 local TV services, which will be carried on the first PSB (DIGI-TV) multiplex.

Nationwide coverage was achieved, prior to switchover, for the first DIGI-TV multiplex, carrying DR1, DR2 and TV2, and Boxer services were rolled out from February 2009.

The analogue networks were switched off on the night of 31 October / 1 November 2009, releasing the frequencies required to bring the remaining DTT services into operation. Boxer has launched services on three multiplexes, and a fourth will become available in 2010. The possibility exists that the fourth Boxer multiplex could be used to provide mobile TV services, in which case some capacity must be made available to DR.

On 22 June 2009 the Danish government decided that the frequency band 790-862 MHz be released for non-broadcast use, though the decision as to how this resource will be allocated has not, yet, been made..At least two the Boxer networks make use of channels in the 61-69 range, and will therefore need to be re-planned to allow release of the digital dividend spectrum.

3.7 Netherlands

3.7.1 Historical background

The Netherlands has one of the highest penetration rates in the world for cable TV (>90% of the population), and, as a consequence, analogue off-air reception had declined to the point where it is used mostly in holiday homes and caravans.

[15] Though some local SFN relays are used, e.g. at the two Copenhagen sites

DTT was launched in 2003 by Digitenne (a joint undertaking between KPN, Nozema and a variety of broadcasters) and was aimed at portable and mobile receivers, as the fixed audience was addresses by cable systems. Digitenne hold a 15 year exclusive DVB-T licence.

The interim service was planned on the basis of an MFN, with local SFNs, supporting five multiplexes. The 8k mode of DVB-T was used with 64-QAM modulation.

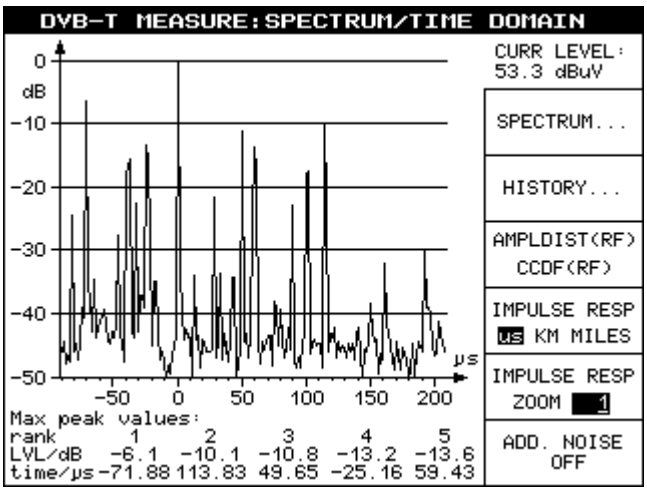
3.7.2 DSO

Switchover occurred in December 2006. The final DTT network, in contrast to, for example France and the UK, represented a complete break with the past. A significantly denser transmitter infrastructure was used, with a larger number of sites operating at lower power. This provided a better service to the main target of portable and mobile receivers, and allowed the use of wide-area SFNs without generating self-interference. As fixed receivers are not a significant market for Digitenne, the questions of antenna pointing and grouping did not arise, as they did in other countries.

The final network provides for four national multiplexes, provided using regional SFNs. In the Amsterdam area, for instance, these uses channels 24, 39, 57 and 64. All multiplexes use 64-QAM modulation in the 8k mode with a ¼ guard interval. A fifth national network is used to provide mobile TV, using the DVB-H standard.

In all, channels between 61 and 66 are used in ten areas (Figure 13 shows the impulse response of transmissions on channel 64, as received on the East coast of the UK, illustrating the density of transmitter deployment on a typical channel). As the existing multiplexes are licensed until 2017, release of these channels may be problematic. Channels 67 and above are not used in the Netherlands DTT plan, and may be available.

Figure 13: Impulse response on Channel 64 showing SFN components (source: Aegis)



3.8 USA

3.8.1 Historical background

The USA provides a contrast to the European examples above, in that the TV broadcast framework has remained essentially unchanged from its inception in [1939], and that it is fundamentally an ad-hoc system that developed piecemeal, rather than being planned as a whole.

Services were licensed by the FCC as applications were received from potential broadcasters. Interference was controlled by applying simple frequency re-use distance constraints. In processing the many license applications made in the 1950s, some effort was made to prioritise those applications that would extend TV services to new areas. As congestion increased on the original VHF frequencies, allocations were increasingly made at UHF; these were generally unpopular with the recipients, as the higher diffraction losses (and the insensitivity of early receivers) limited the coverage areas. Relay stations are seldom used, so most services are provided by a single high power transmitter, rather than via an extensive network as is generally the case in Europe.

3.8.2 Interim network and spectrum release

Following the release of the ATSC standard in 1999, the FCC started to issue licences to allow existing broadcasters to simulcast their programmes digitally. In contrast to the general situation in Europe, there was strong opposition to the use of DTT as a means to allow new entrants – rather, existing stations were keen to guard their (often long-established) service areas. As a consequence, DTT was marketed to consumers as an upgrade path to HDTV. Although ATSC multiplexes often contain more than one service, these are almost invariably offerings by the same broadcaster, and will typically consist of an HDTV programme, an SDTV programme and a news, weather or sports channel. The interim DTT services were generally provided on a ‘taboo’ channel adjacent to the original allocation.

In the US, the UHF band has, historically, been lightly used compared with the European situation. The decision was therefore made to release the top part of the broadcast band for other use. The spectrum in the US is based on a 6 MHz raster, and the channelisation is, therefore different to Europe. The released frequencies were those above channel 52[16] (698 – 806 MHz), representing 32% of the band.

The two figures below show how the 700 MHz spectrum has been divided into the Lower 700 MHz band (formerly TV Channels 52 – 59) and the Upper 700 MHz band (formerly TV Channels 60 – 69) for commercial services.

[16] corresponding to European channel 49

Figure 14: Lower 700 MHz Band

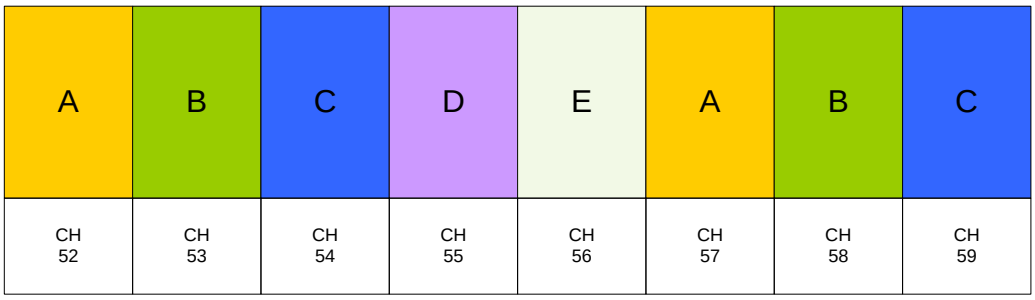
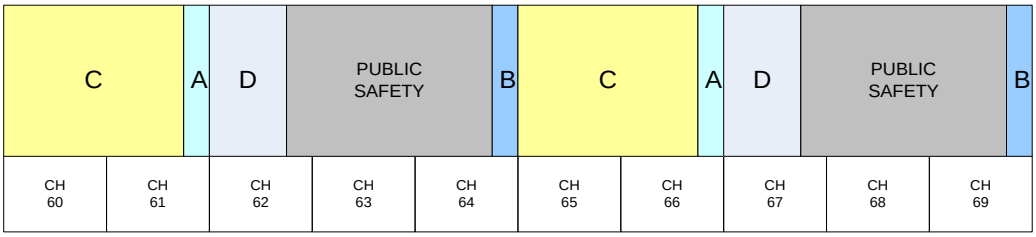


Figure 15: Upper 700 MHz Band



The majority of the spectrum has been awarded by auction with different blocks being awarded based on different geographic areas (e.g. cellular market area (CMA), economic area (EA), regional economic area groupings (REAG), and nationwide) as shown in the table below.

The auctions commenced with the Upper 700 MHz band guard bands (Blocks A and B) in September 2000 (Auction 33) and the licences that were unsold were re-auctioned in February 2001 (Auction 38). The licences were for Band Managers who were to lease the spectrum. The licences were to be valid for approximately 14 years which was expected to be 8 years beyond the date when the incumbent broadcasters were required to have relocated.

Note that the Lower Block A spectrum (698-704 MHz) may not be used within a radius of at least 96.5 km of TV transmitters operating on the adjacent channel51 frequency, to protect the latter services from potential interference from mobile devices.

Blocks C and D in the Lower 700 MHz band were first offered at Auction 44 in August 2002 and unsold licences were re-auctioned in April 2003 (Auction 49). The 5 C-block licences in Puerto Rico were awarded in July 2005 (Auction 60). The expiry date of the licences is 1 January 2015.

The other blocks of spectrum were auctioned at the beginning of 2008 with only Block D[17] in the Upper 700 MHz band not meeting the reserve price. The initial authorisation was for a term, not to exceed 10 years, from 17 February 2009.

Table 3: Auction awards of 700 MHz spectrum

Block	Frequencies	Amount of spectrum	Geographic area	Number of licences
Block A (Lower 700 MHz)	698-704, 728-734 MHz	2 x 6 MHz	Economic Area (EA)	176
Block B (Lower 700 MHz)	704-710, 734-740 MHz	2 x 6 MHz	Cellular Market Area (CMA)	734
Block C (Lower 700 MHz)	710-716 MHz 740-746 MHz	2 x 6 MHz	Cellular Market Area (CMA)	734
Block D (Lower 700 MHz)	716-722 MHz	6 MHz unpaired	Economic Area Groupings (EAG)	6
Block E (Lower 700 MHz)	722-728 MHz	6 MHz unpaired	Economic Area (EA)	176
Block A (Upper 700 MHz)	757-758, 787-788 2 MHz	2 x 1 MHz	Economic Area (MEA)	52
Block B (Upper 700 MHz)	775-776, 805-806 MHz	2 x 1 MHz	(MEA)	52
Block C (Upper 700 MHz)	746-757, 776-787 MHz	2 x 11 MHz	Regional Economic Area Groupings (REAG)	12
Block D (Upper 700 MHz)	758-763, 788-793 MHz	2 x 5 MHz	Nationwide (Public / private partnership)	1
Public Safety	763-775, 793-805 MHz	2 x 12 MHz		

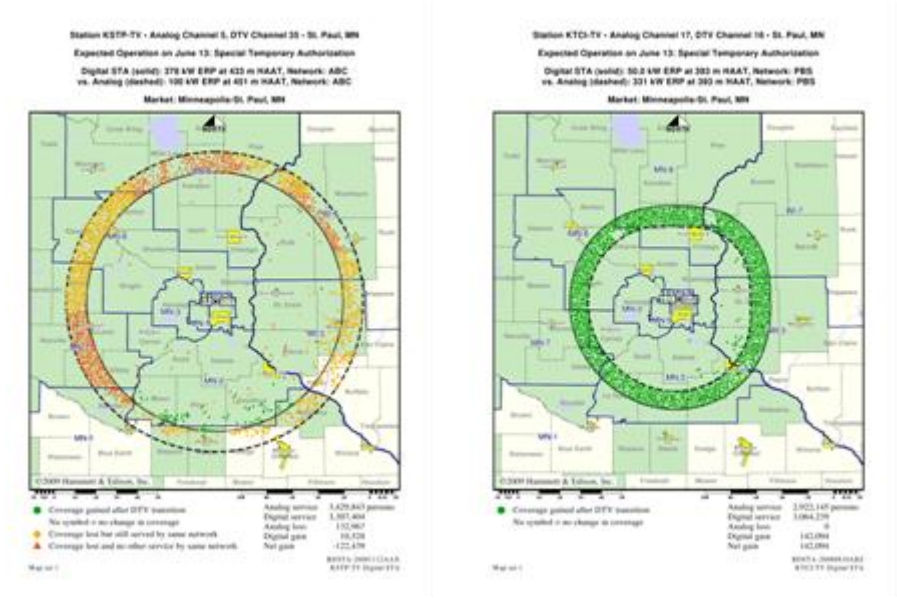
[17] The winner of the D-Block was to form a public-private partnership with the PSST to build out the network.

3.8.3 DSO

Digital switchover occurred throughout the USA in June 2009 (having been delayed from February owing to concerns about public preparedness. With the end of simulcasting, all stations were able to move to full-power digital operation.

In some cases, services have migrated from VHF to UHF; sometimes with consequent reduction in coverage areas (see Fig.8.2).

Figure 16: Comparative analogue & digital service areas for two TV stations in Minnesota (source: FCC)

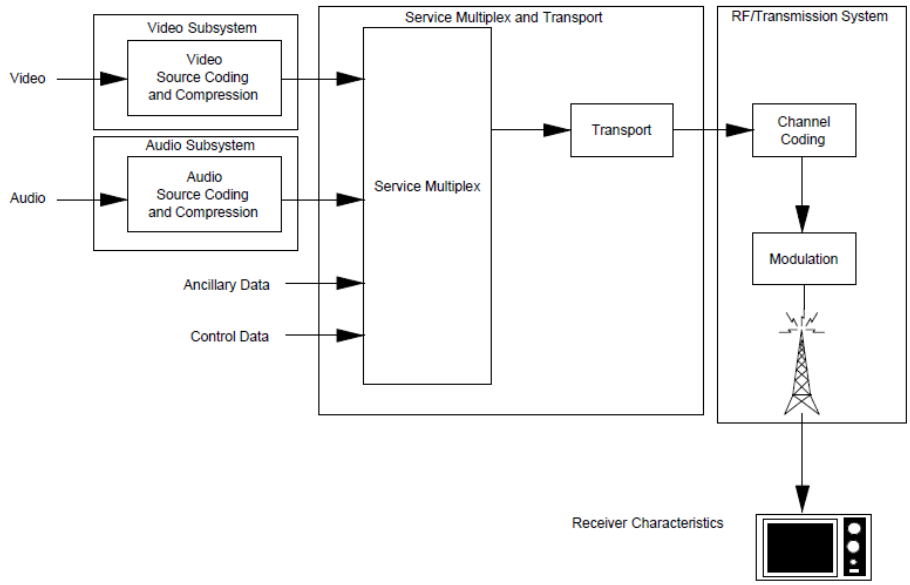


A ANNEX 1 DTT TECHNOLOGIES AND PLANNING PRINCIPLES

A.1 Introduction

This annex presents an overview of the relevant characteristics of each of the three main DTT standards (DVB-T, ATSC and ISDB-T) and a summary of the issues surrounding spectrum and service planning.

Figure 17: Generic DTT system



The figure above gives shows the structure of a generic digital terrestrial TV system. In all the cases considered below, the *Video* and *Audio subsystems* and the *Service Multiplex and Transport* are largely based on MPEG-2 standards. An outline understanding of MPEG-2 is therefore necessary before examining the individual standards in detail.

A.2 The MPEG toolbox

Probably the single most important benefit of the adoption of digital broadcast technologies lies in the opportunity they provide for data compression. While limited opportunities existed in the analogue world for compression (such as the bandwidth reduction of the colour difference signals in PAL), digital methods allow for great flexibility in trading quality (however defined) for capacity.

To give an example of the benefits of compression, a raw 625-line colour picture, digitised so as to preserve all the original information with no additional coding, would require a data rate of 2 bytes x 13.5 MHz = 27 MB/sec = 216 Mbit/s. Using a typical MPEG-2 coder, this is reduced to around 5 Mbit/s for a good quality picture.

All current DTTV systems are based on the use of the MPEG-2 set of standards for "the generic coding of moving pictures and associated audio information". This set of standards provides a toolbox of algorithms and data structures that can be tailored to the specific requirements of particular users.

A.3 Video coding

The most important, and extensive, part of the MPEG-2 toolkit are the video coding algorithms, described in Part 2 of the standard. These allow for a large number of options in terms of the picture resolution, the degree of compression and the complexity of the algorithms used to remove redundancy. As many applications (which may be as diverse as digital video editing on computers, domestic camcorders or professional studio recording) will generally only need a small subset of the available options. The standard is therefore broken down into a number of '*profiles*' which define the algorithms available and *'levels'* which specify the range of parameters (resolution, etc) that can be accommodated. All the digital television systems described here specify the main profile at either the high level (MP@HL) or at medium level (MP@ML).

The MPEG video coding methods are based on the use of the discrete cosine transform (DCT) to code small blocks of the image in spatial frequency terms. It is then simple to discard the higher frequency terms (representing the fine detail), thus implementing (lossy) compression. The set of coefficients can then be (losslessly) compressed using variable length coding.

In MPEG video coding , only a few frames (intra-pictures) of the picture are sent as described, with the remainder using 'motion vectors' to code the movement of bulk elements of the scene between frames (e.g. a moving car, or the effect of a panning camera), and thus interpolate between the reference frames.

If a constant bitrate transmission is required, buffering may be used, with feedback to steer the spatial filtering of the DCT depending on buffer fullness.

Current DVB-T transmissions (and DVDs) use the above methods, with the chrominance signal compressed by a factor of two both vertically and horizontally. MPEG-2 coding will reduce the raw bitrate of a digital TV signal sampled according to CCIR Recommendation 601, from 124 Mbit/s to between around 3-15 Mbit/s.

A.4 Audio coding

The Original MPEG-2 specification added a few extensions to the well-known MP3 audio compression format (Confusingly, MP3 is a shorthand for MPEG1, audio layer III). In 1997, the Advanced Audio Compression (AAC) algorithm was added to the MPEG-2 specification.

A.5 Transport stream

The MPEG specification defines a transport stream (TS), essentially a packet-based system through which the video, audio and data information associated with one or more 'programmes' can be multiplexed onto a single data stream.

MPEG-2 TS packets are 188 bytes long, but allowance is made for particular applications to add further additional bytes for error correction. Thus, DVB-T adds 16 bytes of FEC). Each packet carried a Packet ID (PID) which associates it with a programme. The TS also includes fields for many other purposes including synchronisation and the addition of null packets to ensure constant TS bitrate.

A.6 MPEG-4

The capabilities and performance of MPEG-2 were extended with the release of MPEG-4, first released in 1998 and still evolving. The key enhancement, in the context of this study, is in Part 10 of the standard covering "Advanced Video Coding" or 'AVC'. This describes video compression algorithms, also standardised as ITU-T H.264, that offer significantly better performance than is available within MPEG-2. Thus an HDTV picture coded using MPEG-2 might require some 20 Mbit/s while MPEG-4 coding could reduce this to around 8 Mbit/s.

MPEG-4 video coding (Layer 10 or AVC) improves on the compression achieved in MPEG-2 by the use of enhancements of the techniques described, including variable block-size motion compensation, which allows more accurate isolation of moving elements of the scene and the ability to use neighbouring DCT blocks to improve spatial prediction. A more flexible use of previously encoded pictures for motion vector estimation is also possible.

The 'high' profile of MPEG-4 Layer 10 is used by the BBC and Sky in the UK for their satellite HD offerings, and will be used for the new terrestrial HD multiplex (MUX B). Bit rates are less than half those that would be achieved using MPEG-2 coding.

It should be noted that both MPEG-2 and MPEG-4 can be used for the carriage of standard (SDTV) or high definition (HDTV) video.

A.7 The DVB-T standard

A.7.1 Overview

Within Europe, digital TV standardisation has been agreed under the aegis of the DVB[18] project. The terrestrial standard, DVB-T, is one of a family of standards that includes DVB-C for cable and DVB-S for satellite.

Common to all these transmission standards is the use of MPEG standards for source (video and audio) coding. The MPEG data, together with associated data (service information, SI, and interactive services) is carried in an MPEG-2 'Transport

[18] Digital Video Broadcasting

Stream', with additional FEC coding, and is used to modulate a radio frequency carrier in a manner appropriate to the application.

A key concept of the DVB standards is that of the 'multiplex', in which a number of video, audio and data streams are combined into a single transport stream. The details of this combination can be dynamic, with space on the multiplex being re-assigned, for example, at different times of the day (e.g. the space occupied in the daytime by the CBeebies children's channel is re-allocated in the evening to the BBC4 arts channel. This flexibility can also be used on a much finer scale to allow 'statistical multiplexing'. Video coders can be configured so that the instantaneous bit rate on the output depends on the complexity of the scene being coded – a shot of an interviewer in a studio will require a much smaller bit-rate than a fast-moving football match taking place against a backdrop of trees. With statistical multiplexing, it is assumed that peaks of bit rate are unlikely to occur simultaneously across several channels, and each can therefore be allocated spare capacity on the multiplex as required. This results in a considerable saving compared to the case where each channel requires a ring-fenced amount of bit-rate sufficient to cope with occasional peaks. The use of statistical multiplexing (StatMux) does, however, require a degree of cooperation and trust between the broadcasters involved.

In DVB-T, the data in the transport stream is modulated using Coded Orthogonal Frequency Division Modulation, in which the data is spread across a large number (either 1705 or 6817, referred to as '2k' or '8k' modes) which occupy the chosen RF channel (8 MHz at UHF in Europe, but 7 or 6 MHz variants are also specified). This spreading confers several advantages; firstly, the data rate on each carrier is sufficiently low that channel dispersion doesn't cause inter-symbol interference and, secondly, the spreading of the data across a wide bandwidth (combined with appropriate coding) gives a high resistance to frequency selective fading and CW interference.

The COFDM carriers can be modulated using QPSK, 16-QAM or 64-QAM, allowing a broadcaster to make a trade-off between overall data rate and signal robustness (i.e. power requirement or coverage area). A range of values are also permitted for the inner code rate, between $^1/_2$ and $^7/_8$.

A.7.2 Guard interval and single frequency networks

A characteristic of the COFDM technique, which is particularly relevant to this study, is its ability to operate in conditions of severe multipath (the 'ghosting' seen on analogue TV receivers). The length of each transmitted COFDM symbol (the 'useful symbol time, or T_u') is extended by a certain 'guard interval' or GI. The demodulator, however, only 'reads' the symbol during a period 'T_u', allowing multipath energy to fall harmlessly within the guard interval. Values of guard interval between $^1/_4$ and $^1/_{32}$ are available. This is a useful technique for improving signal robustness in urban or mountainous areas, especially where low-gain (e.g. mobile) aerials are used.

A more dramatic advantage, however, can be realised if it is appreciated that there is no difference between a delayed signal reflected from a tower block, and a signal

from a distant transmitter carrying the same programme material. The implication is that multiple transmitters can operate on the same frequency, if the guard interval used is adequate to protect against interference from distant transmitters. It becomes possible, therefore, to operate extensive transmitter networks on a single frequency, the so-called 'Single Frequency Network' or SFN.

The penalty for this saving in frequency resource is, however, that the bit-rate available for programme content is reduced. Furthermore, the maximum guard interval in DVB-T is limited to 224µs, corresponding to a distance of ~67km, a value that is not large enough to allow SFN operation in certain cases (large areas with little natural isolation between transmitters - the South coast of the UK is an example).

Table 4: DVB-T parameters

		C/N	Data rate (Mbit/s)			
Modulation	**Code Rate**	**(QEF)**	**GI=1/4**	**GI=1/8**	**GI=1/16**	**GI=1/32**
QPSK	1/2	4.1	5.0	5.5	5.9	6.0
	2/3	6.1	6.6	7.4	7.8	8.0
	3/4	7.2	7.5	8.3	8.8	9.1
	5/6	8.5	8.3	9.2	9.8	10.1
	7/8	9.2	8.7	9.7	10.3	10.6
16-QAM	1/2	9.8	10.0	11.1	11.7	12.1
	2/3	12.1	13.3	14.8	15.6	16.1
	3/4	13.4	14.9	16.6	17.6	18.1
	5/6	14.8	16.6	18.4	19.5	20.1
	7/8	15.7	17.4	19.4	20.5	21.1
64-QAM	1/2	14.3	14.9	16.6	17.6	18.1
	2/3	17.3	19.9	22.1	23.4	24.1
	3/4	18.9	22.4	24.9	26.4	27.1
	5/6	20.4	24.9	27.7	29.3	30.2
	7/8	21.3	26.1	29.0	30.7	31.7

The table above summarises some of the different options available within the DVB-T system; the parameters used in the post-DSO UK network are highlighted.

A.7.3 Video coding

The details of the implementation of the DVB-T standard tend to differ on a country-by-country basis, with each administration, or groups of administrations, publishing specifications for the capabilities of receivers to be marketed in that area. In most cases the main differences relate to the way in which interactive services, service information and electronic programme guides are handled. However, different options have also been chosen for the video coding.

Thus, in the UK, it is required that decoding support MPEG-2 medium profile at the medium layer (MP@ML), thus for pictures with a resolution of up to 720 x 576 pixels,

or a standard definition picture. In Australia, on the other hand, support of the High Level is mandated, to support HDTV transmission.

A more complicated situation exists in France, where some DVB-T transmissions are making use of MPEG-4 AVC, while others use the less-efficient MPEG-2 (see WP2 report for further discussion).

A.7.4 DVB-T2

This recently-adopted (summer 2008) upgrade to the DVB-T standard offers very significant capacity improvements, as well as other benefits. The principal changes in the new standard are a greatly improved coding scheme (using LDPC/BCH codes) which approaches the Shannon limit as closely as is practicable, combined with the use of higher-order modulation (256 QAM). Other improvements (longer interleaving and the use of 'rotated constellations') add robustness in the face of impulsive noise and adverse propagation channels.

Taken together, early laboratory trials suggest that these improvements can increase the data capacity of a single 8 MHz channel by as much as 50%, without changing the planning assumptions (i.e. there is no requirement to increase transmitter powers or to tolerate smaller coverage areas). This figure, which has yet to be confirmed in large-scale field trials, is significantly in excess of the original target of a 30% improvement. The system also allows more planning flexibility by permitting SFNs to cover a wider geographical area.

The DVB-T2 System is designed from the outset to be received by existing domestic DVB-T antenna systems and to co-exist with existing DVB-T transmissions. The new MPEG-4 (H.264) video codec can be used with DVB-T2 and is approximately 2 times more efficient than MPEG2-video codec used for standard definition channels.

Products and services using DVB-T2 are intended to be available commercially from 2009 and a typical scenario could be the launch of high definition TV services over DVB-T2 on new frequency allotments alongside existing standard definition TV services using DVB-T, after analogue broadcasts end.

A.8 The ISDB-T standard

A.8.1 Overview

The Japanese ISDB-T standard, standardised by the DiBEG group[19] is similar in some ways to DVB-T, in that, as well as being based on the MPEG-2 coding and transport specifications, it uses COFDM with a flexible multiplexing arrangement for multiple programme streams. The system uses 5617 carriers in a 5.572 MHz bandwidth, fitting within a nominal 6 MHz RF channel. Variants are also available for 7 or 8 MHz channels.

[19] Digital Broadcasting Expert Group

Like DVB-T, a variety of coding rates and modulation types (DQPSK, QPSK, 16-QAM and 64-QAM) are available within the standard. The guard intervals of ¼, $^1/_8$ or $^1/_{16}$ are sufficient to support SFN operation.

As with the other terrestrial systems, the MPEG-2 transport stream packet is extended from 188 bytes, in this case by the addition of 16 bytes of Reed-Solomon coding. The system uses time interleaving to achieve a significantly better performance with respect to impulsive noise than either ATSC or DVB-T[20].

Whereas, however, the multiplexing approach within DVB-T ensures that these is no simple relationship between individual COFDM carriers and programme streams, in ISDB, the 5617 carriers are grouped in 13 contiguous 'segments' of 432 carriers. The central segment is reserved for mobile TV use, while the others may be flexibly allocated to carry programme streams. For example, all 12 segments may be allocated to support a single HDTV channel, or three SDTV channels may be supported using three groups of four segments.

The audio coding in ISDB-T uses the MPEG-2 AAC codec.

A.8.2 Adoption

Japan adopted the system in 2003, and the DiBEG group reported a total of 20 million receivers in June 2007.

In 2006 Brazil adopted a modified version of the standard, incorporating MPEG-4/AVC video coding, and a new interactive engine. This 'ISDB-Tb' standard has since been adopted by the DiBEG group, as 'ISDB-T international).

Following the lead of Brazil, and to the distress of the DVB and ATSC camps, the ISDB-T international standard has been adopted widely in Latin America. To date Argentina, Brazil, Peru, Chile and Venezuela have adopted the standard.

A.8.3 The '1seg' mobile standard

The central segment mentioned above, of 428 kHz bandwidth, is reserved for mobile broadcasting marketed under the '1seg' name. The service uses the H.264 video coding standard with AAC sound, and delivers low-resolution video (320 x 240 pixels).

Importantly, the standard allows for 'partial reception'; in other words the receiver does not need to process the whole COFDM signal, if only one segment is to be decoded. This allows for significant simplification of receivers and a reduction in power consumption.

The service was rolled out across Japan in 2006.

[20] Though the new DVB-T2 specification also provides much better resistance to impulsive interference through interleaving.

A.9 The ATSC standard

The American ATSC standard was published in 1995 by a consortium of companies and industry bodies that amalgamated a number of previous proposals in a so-called 'Grand Alliance'.

The American ATSC system is unique in its use of a single carrier system, which offers less robust performance in areas prone to multipath. Furthermore, the standard is not inherently suitable for SFN use, although advanced receiver design, and careful network dimensioning has allowed the deployment of a form of SFN in a limited number of cases.

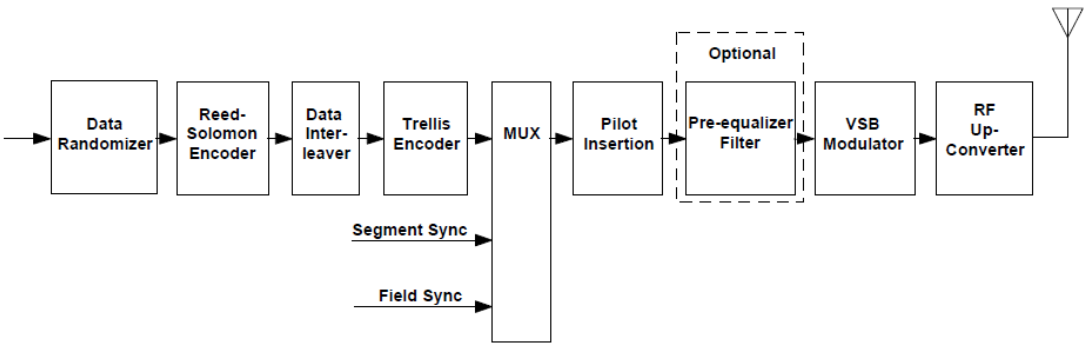
Unlike the DVB-T and ISDB-T systems which use COFDM to provide resilience to multipath, the ATSC standard makes use of a single carrier modulation system. The 8VSB modulation scheme uses 8-level amplitude modulation of the carrier. Such an AM process generates two redundant sidebands, and one of these is therefore removed using a 'vestigial sideband' (VSB) filter. This approach is comparable with that used for all analogue TV systems, in which VSB filtering is employed.

It is claimed that the reasons for the adoption of the 8VSB standard were that it avoids the high peak-to-average-power ratio of COFDM systems and offers somewhat better C/I performance, but there must be some suspicion that the real motive was related to commercial and IPR considerations, as the disadvantages seem to outweigh these minor benefits. A significant lobbying campaign around the turn of the century attempted to overturn the choice of 8VSB.

The system is designed to operate in a 6 MHz RF channel and supporting a bit-rate of 19.4 Mbit/s. Unlike the DVB-T or ISDB-T systems, there is no option for the selection of modulation parameters or code rates to suit particular contexts.

Video coding makes use of the MPEG2 standard, and the standard formally allows three formats (1080 x 1920, 720 x 1280 and 480 x 702), although many stations, in practice, make use of other resolutions available within the MPEG-2 profile.

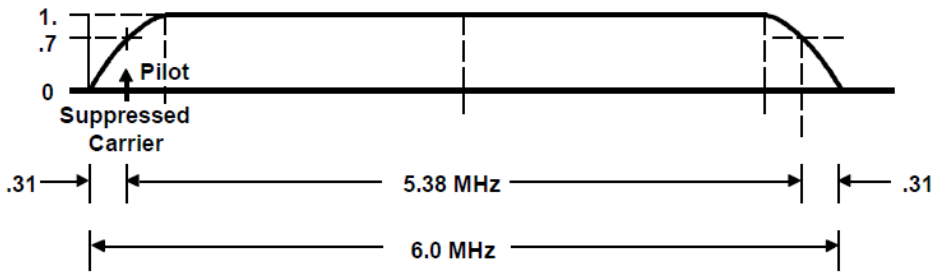
Figure 18: ATSC (8VSB) transmitter



Following randomisation and Reed-Solomon encoding, the data is grouped into ‘fields’ each containing 313 data segments. The first of these is a synchronising signal that includes the training sequence used by the receiver equaliser.

Suppressed carrier amplitude modulation is used, in which each symbol may have one of eight discrete levels; each symbol therefore codes three bits of data. The redundant data in the lower sideband is removed by filtering before transmission, and a pilot tone added at the suppressed carrier frequency. The resulting spectrum is as shown in Figure 19.

Figure 19: Spectrum of ATSC (8VSB) signal



Unlike the DVB-T standard, the focus of ATSC development was to provide a means by which existing TV stations might upgrade to HDTV. As such, the usual configuration is for the multiplex to carry a single HDTV stream, and one or two SD programmes.

A.10 System Comparison

All three systems have a great deal in common, particularly the use of the algorithms and structures provided in the MPEG-2 specification.

The ATSC is somewhat inflexible, having been optimised for a particular market (single TV stations serving a large rural area). In particular, the lack of support for single frequency networks, and the use of MPEG-2 coding for HDTV implies a potentially poor spectrum efficiency.

The DVB-T system is both more flexible and more robust, allowing transmissions to be tailored to particular circumstances. If used (as in Australia) to provide HDTV services, spectrum efficiency is rather poor; local variations of the standard (as in e.g. France) are adopting the MPEG-4 codec, however. The DVB-T2 standard combines this codec with a more efficient coding and modulation scheme, allowing the Shannon limit to be closely approached.

The ISDB-T system has the versatility of DVB-T, coupled with an integrated means of delivering mobile TV services to small terminals. The international version also integrates the more efficient MPEG-4 video coding into the standard.

In terms of the high-level RF planning parameters, tabulated below, there are no dramatic differences between the systems.

Table 5 Comparative characteristics of DTT systems

	DVB-T (16-QAM, 2/3)	**DVB-T (64-QAM, 2/3)**	**ATSC**	**ISDB-T (64-QAM, 2/3)**
Bandwidth	8 MHz	8 MHz	6 MHz	6 MHz
TS Data rate	16.1 Mbit/s	24.1 Mbit/s	19.4 Mbit/s	19 Mbps
C/N	11.6 dB	17.3 dB	14.9 dB awgn	
Co-channel	14 dB	20 dB	15 dB	20 dB
ACI	-30 dB	-30 dB	-27 dB	-26 / -27 dB
Minimum FS[#]	40 dBµV/m	46 dBµV/m	39 dBµV/m	46 dBµV/m

[#] *No allowance for location variability. Assumes 10dBd antenna gain. F=615 MHz*

A.11 DTT Planning

A.11.1 Introduction

At the highest level, such planning is determined by international agreements such as the 'Regional Radiocommunication Conference' held in Geneva in 2006 (GE-06). Although this conference allocates frequency resources to individual administrations, the detail of how these are used to implement specific networks is not defined, and will generally be the subject of a significant national planning process.

The criteria, methods and procedures for all levels of DTT planning *will be described*, in sufficient detail to understand the impact of the choices made on overall spectrum efficiency.

This work package *will also include* an outline of the spectrum requirements for a number of simple, hypothetical, scenarios (e.g. national coverage for rooftop aerial reception using MPEG2 to support 7 programme channels).

The text provided in this Work Package *will provide* the background necessary for a robust understanding of the case studies in the two remaining WP

A.11.2 Planning parameters

A.11.2.1 Introduction

A terrestrial broadcaster, regardless of whether the service is analogue or digital, radio or TV, medium wave or UHF, will undertake to provide a specified field strength (generally given in decibels relative to one microvolt per metre, or dBµV/m) within an given area.

The choice of this field strength must take into account many factors, a few of which are precisely defined by the laws of physics, but the majority of which relate to the

statistics of receiver and aerial performance, or of radiowave propagation. These will generally include:

- The minimum voltage that must be present at the receiver aerial socket for it to provide an 'acceptable' level of service
- An allowance for the loss of the aerial feeder cable
- An allowance for the gain (if any) of the aerial (generally in dB relative to a dipole, dBd)
- The appropriate conversion factor for relating the field strength in which a dipole is immersed to the voltage appearing across the terminals. This depends only on frequency
- An allowance for additional margin required to overcome interference from other services on the same, or adjacent channels
- An allowance for interference from man-made noise
- Allowances for other factors such as multipath and transmitter performance

If all these factors are taken into account, it would be possible to ensure acceptable reception at a specified fixed location. Broadcast services, however, are offered to receivers that will be randomly located throughout an area, and an additional allowance must therefore be made for 'location variability'. It is typically assumed that the minimum required field strength should be provided to between 70% - 95% of locations within an area.

Each of these factors will be considered further, below.

A.11.2.2 Minimum terminated voltage

For analogue services it was necessary to determine the minimum required signal at a receiver based on subjective assessment by large samples of 'typical' listeners of viewers. The situation is somewhat simpler in the case of digital services, as the quality of reception will generally degrade very quickly from perfect to non-existent over a range of a few dB (the 'digital cliff-edge'). For a given codec (e.g. MPEG-2) the required BER is quite well defined. In turn, for a given modulation scheme and code rate, the carrier to noise (C/N) ratio that will result in a given BER is also readily defined, although this is complicated for real propagation channels.

The C/N values required for different code rates and orders of modulation have been determined by simulation, and are given in the current (2009) DVB-T specification. For the post-DSO mode in the UK, the value is 17.3dB.

It should be noted that somewhat different values for this parameter are in use, with different empirical allowances being made for aspects of receiver design or of the propagation channel. For example, the C/N value used in the RRC-06 plan was 19.5dB, also for a 64-QAM, 2/3 DVB-T system.

A.11.2.3 Receiver noise

Given the required C/N ratio, the voltage (or power) required at the receiver input can be determined by calculating the noise power in the receiver system.

The representative noise figure used in the RRC process was 7dB, assumed to apply throughout the UHF band. The noise power, P_n in the receiver bandwidth is calculated using:

$$P_n = kTB\ (Watts)$$

Where:

K = (Boltzmann's constant = 1.38×10^{-23} J/K

T = absolute temperature = (typ) 290K

B = system noise bandwidth = 7.61×10^6 Hz

This calculation gives a power of 3.05×10^{14} W, or -135.2dBW (-105.2dBm). The receive system noise factor must be added to this figure, for example:

-105.2 dBm + 7dB = -98.2 dBm

Adding the necessary C/N (e.g. 22.8 dB) gives the required receiver input power of -75.4 dBm. This can be converted to the equivalent effective voltage by:

Voltage (dBμV) = Power (dBm) +108.75 (for a 75Ω system)

Thus a domestic receiver requires a minimum input signal of **33.4 dBμV.**

A.11.2.4 Aerial system performance

The amount of energy which a dipole antenna can extract from a given electric field will depend on its 'effective length' given by $\left(\frac{\lambda}{\pi}\right)$. If a dipole is subject to a field strength of *e* (V/m) at a wavelength λ (m), the voltage (EMF) across its terminals will be:

$$e.\left(\frac{\lambda}{\pi}\right)$$

and the terminated voltage (PD) will be half this value.

This can be more conveniently expressed as:

V_{pd} (dBμV) = e (dBμV/m) + 20 log(95.5/*f*) - 6.0

Where *f* is in MHz.

A.11.2.5 Variation of effective aperture with frequency

Thus, at 500 MHz, a field strength of **53.8 dBμV/m** would be required to give a terminated voltage of 33.4 dBμV. To attain the same terminated voltage at 800 MHz would require a field strength of **57.9 dBμV/m.**

For analogue planning, where the degradation of picture quality with decreasing signal is gentle, the useful simplification was made of adopting fixed coverage limits for the whole of Band IV and for the whole of Band V. With the digital 'cliff edge', this is no longer possible, and most planning is undertaken on the basis of calculating the actual effective aperture for each UHF channel, a 20 log (f) dependence.

A.11.2.6 Aerial system gain

In most cases the aerial will have gain relative to that of a dipole, and will be connected to the receiver by a length of feeder.

An overall system gain of 10dBd is generally assumed for rooftop aerials, although the detailed apportionment between aerial gain and feeder loss can vary. In the RRC-06 process values of 10dBd / 3dB were assumed in Band IV and 12dBd / 5dB in Band V.

Recent work in the UK has confirmed previous findings that the actual aerial system gain in domestic installations tends to be related to the typical field strengths in the area. Overall system gain figures of 7dB are generally only found where the analogue field strength is close to the coverage limit. Where excess field strength is available, the aerial systems are generally correspondingly poorer.

A.11.2.7 Location variability

Following the steps detailed above, it is possible to specify the minimum field strength that would be needed at a specific location to allow a DTT receiver to work. In broadcasting, however, it is not possible to deal with specific locations, but only with statistical generalisations. At UHF frequencies, field strengths can vary by tens of decibels over short distances. What is required, therefore, is a criterion by which it can be ensured that a given proportion of receivers within a nominal coverage area will operate correctly.

When multipath effects are averaged, field strength is found to vary according to a lognormal statistical distribution, over areas across which there is no significant difference in the median field strength. This variation is due to local diffraction losses from nearby buildings, trees and other clutter. In planning analogue services, a standard deviation for this variability of 8dB was often assumed, but this included an element of multipath fading. Several sets of measurements have suggested that a standard deviation of 5.5dB is representative of the location variability experienced for wideband signals such as DTT, and this figure was used at RRC-06.

The assumption of lognormal fading with a standard deviation of 5.5 dB implies that, if 70% of households in an area are to receive a field strength above the minimum value, the median field strength in that area must be 2.86 dB above the minimum value. For other percentage-locations the values are shown in table 6 below.

The ‘reference planning configuration’ adopted in RRC-06 for rooftop reception (RPC1) assumes that 95% of locations will be served, implying a *median* field strength in an area of ~9dB above the minimum value required by a specific receiver.

For the 64-QAM, 2/3 variant, with a C/N requirement of 22.8dB, a median field strength of **53.8 dBµV/m** is required to assure reception at 90% of households within the area.

Table 6 Location variability correction

locations	Median value w.r.t. minimum FS
50%	0.00 dB
70%	2.88 dB
90%	7.05 dB
95%	9.05 dB
99%	12.80 dB

A.11.2.8 Interference

The discussion above has made the implicit assumption that no interfering signals are present, i.e. that the service is '*noise limited*'. While this condition is normal for some radio services, such as satellite downlinks, it is very much the exception for broadcast planning.

The high density of terrestrial broadcast transmitter deployment generally means that significant co-channel power is present from unwanted transmissions. The impact of such interference is to raise the minimum field strength required from the wanted transmitter, so as to preserve the required carrier to interference (C/I) ratio[21]. It is usual to refer to the field strength required to meet both the noise limit and to exceed the C/I requirement as the 'protected field strength' (PFS). The C/I ratio is usually referred to as a 'protection ratio' in broadcast engineering.

It might seem that it would only be necessary to add the required protection ratio to the measured or predicted interferer field strength; however, the interfering signal will exhibit location variability in the same way as the wanted signal, and their *joint* statistics must be taken into account.

The location variability of the ratio of two uncorrelated, log-normally distributed signals is given by:

$$\sigma_{ratio} = \sqrt{\sigma_{wanted}{}^2 + \sigma_{interference}{}^2}$$

Thus, if it is assumed that the wanted and interfering signals have the same location variability of 5.5dB, the joint distribution will have a location variability of 7.8dB.

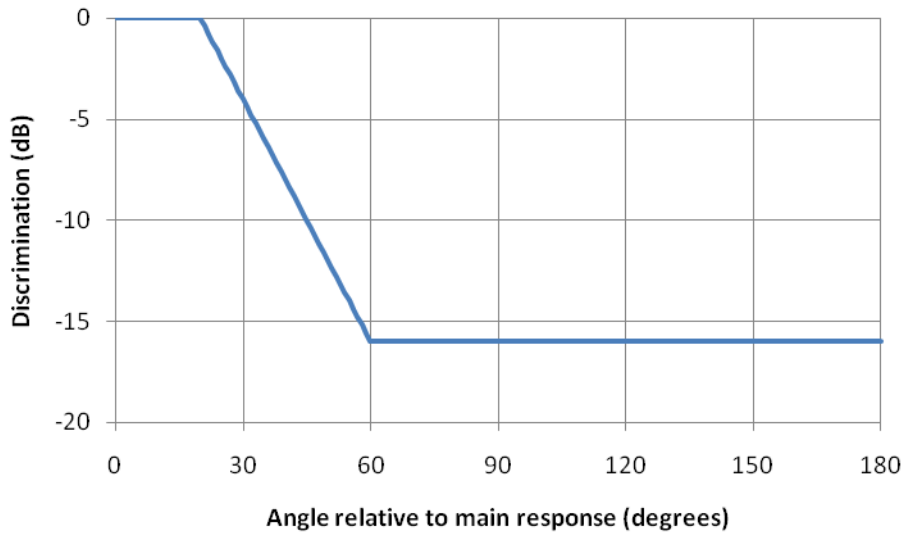
In practice, the overall interference is likely to be the sum of several contributing signals, and in this case determining the statistics of the overall interference distribution is no longer straightforward. In many planning models, the well-known Schwarz and Yeh algorithm is applied. This estimates the overall distribution of the sum of a number of interferers from their individual median values and standard

[21] Actually the carrier to noise and interference ratio, C/(N+I)

deviations. It is assumed that the latter is always 5.5dB, and that all contributions are uncorrelated.

Before calculating the overall interfering field distribution, receive aerial directivity and polarisation discrimination must be applied to each contribution. ITU-R Recommendation P.419-3 gives the directivity shown in Figure 20 below, with a discrimination of 16dB available from the use of orthogonal polarisation.

Figure 20 Domestic aerial directivity assumed in UK planning (from BT.419-3)



The total discrimination from both mechanisms is capped at 16dB. These values are adopted in UK planning.

A.11.3 Planning regimes

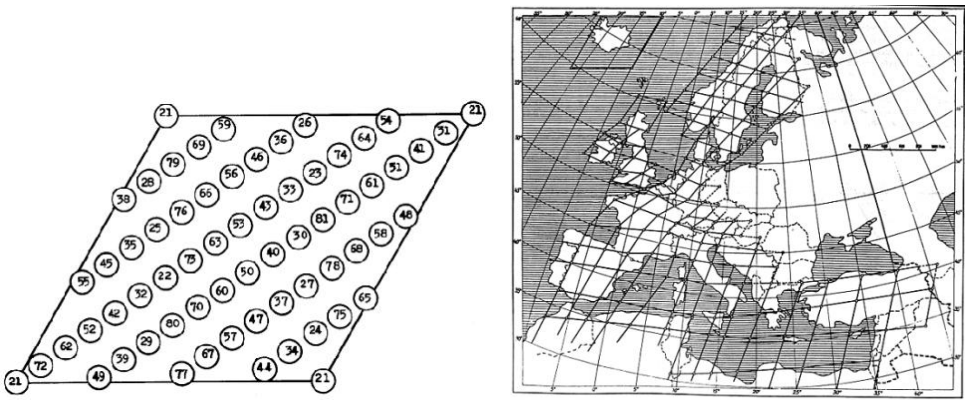
A.11.3.1 International planning

There are few areas of the world in which spectrum planning can be undertaken in isolation; in most cases detailed co-ordination with neighbouring administrations will be necessary.

In Europe, the basis for the original UHF television services was the 'Stockholm Plan' of 1961. In this agreement, the frequency resources were apportioned between administrations on the basis of a set of tentative assignments[22] on a regular lattice. The lattice dimensions and the assumed height and powers of the transmitter were chosen to give acceptable levels of interference.

[22] An 'assignment' is the right to use a frequency at a given location, with a specified power, height, etc.

Figure 21: Theoretical and distorted lattices from ST-61 plan



The resulting lattice of assignments was then distorted to fit the proposed locations of transmitting stations, and further distorted to account for propagation (better over water), the use of directional antennas, differing transmitter powers and other case-specific features.

The Stockholm plan only made assignments for the most powerful transmitters; smaller sites were added as the network planning and deployment proceeded in each country, with the plan being modified on a continuous basis with much bi-lateral and multi-lateral coordination over the years.

An alternative to such assignment planning is to plan on the basis of allotments. In this case, rather than associating a frequency with a particular site, an allotment confers the right to use the frequency anywhere within a given area. This is of particular relevance for single frequency networks (SFN) where a large number of co-channel transmitters may be scattered over an area, and where it becomes technically simple to add transmitters to the network as needed. To determine the position of each site, prior to international planning would be onerous, and is unnecessary if certain network characteristics can be assumed (pattern and density of site distribution, power, and directionality). These characteristics are captured as ‘Reference Networks’ (see Figure 22). Such allotment planning was used (for example) at the Maastricht DAB planning conference in 2002.

For the Regional Radio Conference held in 2006 (RRC-06) for the re-planning of the UHF broadcast band, both approaches were used. Administrations could submit required assignments, if specific sites were already identified (as was the case in the UK), or request allotments, where the details of the a new network had not been fully established (as in the Netherlands).

Figure 22: Showing allotments requested by France in the RRC-06 process

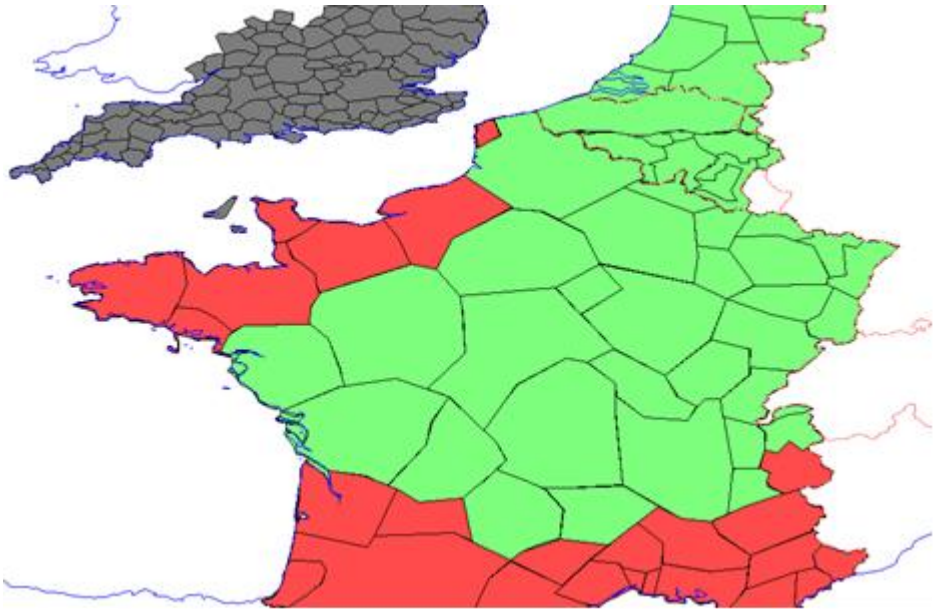
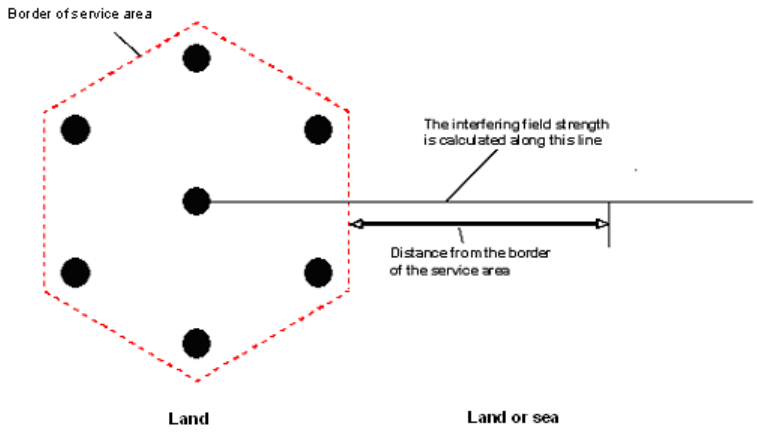


Figure 23: A hypothetical transmitter Reference Network (RN) for use in allotment planning



A.11.3.2 National planning

Having obtained a pool of frequency resources through co-ordination with ones neighbours (or even before doing so), it will be necessary to undertake the detailed local planning of national broadcast networks.

The main distinction between approaches to detailed network planning is between the centrally-planed approach found, for example, in most European countries, and the ad-hoc approach adopted in the USA and elsewhere.

In the UK, for instance, the government determined in the early 1960s that uniform nationwide coverage of four[23] programme channels would be provided at UHF, extending to as near to 100% of population coverage as practicable. It was also mandated that transmitter sites be shared by all four services.

This contrasts with the situation in the USA, where TV broadcasts licences were simply issued by the FCC in response to applications form potential local broadcasters. Although there was much debate in the 1950s as to the best way to promote national coverage of television services the process was left to the market. As a consequence, the number of channels that are available from terrestrial transmitters varies dramatically across the country, and it is often the case that multiple aerials are required, pointing in different directions.

[23] In the event, the fourth channel was not brought into use for some twenty years.