Spectrum usage and requirements

— for future terrestrial broadcast applications

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This article investigates the potential of digital terrestrial television to provide a competitive platform for future broadcasting applications. High-definition TV (HD) is assumed as a future standard for all TV applications. The number of programmes that can be accommodated in a multiplex when applying new source coding techniques (MPEG-4) and new channel coding techniques (DVB-T2) is assessed and the possibilities available within the GE06 Agreement are discussed.

1. Introduction

Faced with the imminent closure of analogue television services, a growing number of European countries are introducing Digital Terrestrial Television (DTT) as a replacement. According to a publication of the EBU [1], 40% of European households use terrestrial television. As the date for full adoption of DTT approaches, there is a need to examine ways of future implementation of the DTT platform in a way that allows for the most efficient use of the spectrum.

An amount of spectrum in the UHF band will be available for usage as a result of the analogue-to-digital switchover (often referred to as “digital switchover”, DSO). In most countries, at least the following three switchover phases are foreseen [2]:

- conversion from analogue to SDTV using MPEG-2;
- conversion from MPEG-2 to MPEG-4/AVC;
- transition from SDTV to HDTV.

Though the first two phases will reduce the use of spectrum for a given amount of programmes, the third phase will require more spectrum for its implementation. According to an EBU study [3], it was predicted that all programmes in the future will be in HD quality and a minimum of 20 to 25 HDTV programmes will need to be provided in order to make it attractive to viewers. Transmission capacity for HDTV can be increased by using advanced transmission systems such as DVB-T2 instead of DVB-T. The use of MPEG-4 compression techniques can also improve transmission capacity.

This article examines how the DTT platform could be restructured in a way that improves spectrum efficiency and how this could be used to facilitate the carriage of HD services. The article also examines how the use of DTT restructuring can fit into the GE06 Plan, in order to ensure adequate coverage and interference-free broadcast networks.

2. Current broadcast platforms in Europe

Traditionally, terrestrial television services were delivered using analogue technology. However, digital terrestrial television using the DVB-T standard makes it possible to deliver the same services in digital quality. Unlike analogue services, digital terrestrial services are carried in multiplexes. Each DVB-T multiplex can support a number of broadcast services, depending on the modulation and coding parameters used.

Apart from using the spectrum more efficiently, digital television provides a lot of flexibility in terms of new services. Examples of services offered include:

- Standard Definition Television (SDTV) with rooftop, indoor and outdoor reception;
- High Definition Television (HDTV);
- Mobile Television; and
- Interactive and data services.

The implementation of digital television in Europe has been done on different broadcast platforms. Only a mixture of platforms can deliver universal access to broadcasting. In the digital environment, the terrestrial platform plays a vital role in the delivery of broadcast services because it is able to offer reception on mobile and portable equipment, and also free-view services. As two examples, this section gives an overview of the DTT services provided in France and Germany. It should be noted that some of the described multiplexes are not yet fully implemented.

2.1. *DTT in France*

DTT started in France in the year 2005, using DVB-T. The services use six multiplexes and the DTT network is, in major parts, a Multi-Frequency Network (MFN). All the multiplexes make use of 64-QAM, GI 1/32, FEC 2/3 and carrier type 8k, giving a multiplex capacity of 24.1 Mbit/s, [4].

In France, rooftop reception is the basic requirement for DTT. The terrestrial platform has a relatively high television household penetration of more than 60%, with less than 40% of households having access to cable and satellite.

The utilization of the seven multiplexes is summarized in *Table 1* [5].

Table 1
DTT multiplex use in France

Multiplex	Modulation	GI	FEC rate	FFT	Capacity (Mbit/s)	Content	Compression
RI	64-QAM	1/32	2/3	8k	24.10	6 SDTV programmes	MPEG-2
R2	64-QAM	1/32	2/3	8k	24.10	6 SDTV programmes	MPEG-2
R3	64-QAM	1/32	2/3	8k	24.10	5 SDTV programmes, 1 HDTV programme	MPEG-4
R4	64-QAM	1/32	2/3	8k	24.10	4 SDTV programmes, 1 HDTV programme	Mixed MPEG-2 and MPEG-4
R5	64-QAM	1/32	2/3	8k	24.10	3 HDTV programmes	MPEG-4
R6	64-QAM	1/32	2/3	8k	24.10	7 SDTV programmes	Mixed MPEG-2 and MPEG-4

As shown in the table, there are many SDTV programmes with only five HDTV programmes (four free-view and one pay-television). The HDTV channels were launched in October 2008, using the H.264/MPEG-4/AVC format [6].

2.2. DTT in Germany

In Germany, the television market is dominated by cable and satellite [7] and the role of the DTT platform is to provide portable reception. However, since DTT has been introduced, its uptake has been growing steadily. The digital switchover was completed by the end of 2008.

DTT is received on a regional basis with different multiplexes available in different regions. There are 16 regions in the country and the number of multiplexes in each region varies from three to eight. Most DTT services in Germany use 16-QAM because it is more robust and this is needed for portable reception since, for this reception mode, a more demanding multipath environment is encountered. A large guard interval of ¼ symbol length is used in order to allow the operation of SFNs. The 16-QAM, GI ¼ and FEC 2/3 parameters yield a multiplex capacity of 13.27 Mbit/s. Each of these multiplexes is used for carrying four SDTV programmes with the MPEG-2 compression technique. HDTV is yet to commence in Germany on the terrestrial platform.

In most European countries, there are either only SDTV or just a few HDTV programmes available. This is because of the high multiplex capacity needed for HDTV and the limited spectrum available. However, with the completion of the transition from analogue to digital on the terrestrial platform, there is hope that some spectrum can be freed up in the UHF band, therefore enabling new services – especially HDTV.

3. High-definition television (HDTV)

HDTV is a digital broadcast signal that delivers a widescreen and high-resolution picture. The demand for HD services is driven by factors such as [8]:

- the growing number of households with HD-ready television displays;
- the apparent decrease in quality of SD services on large flat-panel displays;
- the emergence of new HD-capable technologies; and
- the desire to watch high-profile sporting events and movies in HD quality.

The major advantages of HDTV are the wide screen and the high resolution. The resolution of HDTVs are 720p, 1080i and 1080p. The number stands for the number of lines that are used in creating the image. The greater the number of lines used, the better the picture quality. The letter (suffix) describes the method of scanning used to display the picture; either progressive (p) or interlaced (i). Progressive scan processes the images twice as fast and therefore produces a clearer picture.

In HDTV, the picture quality is the main objective and this requires a higher data rate. Therefore, the number of services in a multiplex is limited. However, to create an appealing offering to viewers, it is necessary to provide a relatively high number of services – as a minimum, between 20 and 25 as offered presently with SDTV. The data rates chosen for HDTV vary from country to country in Europe. The UK is advocating the use of 12 Mbit/s with MPEG-4, France started off with about 8 Mbit/s with MPEG-4, and Germany is advocating between 6 and 10 Mbit/s [9]. There is also an EBU recommendation on this subject [10], which gives additional details.

The digital transmission capacity needed to deliver HDTV depends on a number of factors among which are:

- type of compression used;
- the degree to which picture impairments are acceptable;
- whether the HDTV signal is part of a statistical multiplex.

For more details on this topic, see [3], Section 2.

The MPEG-2 compression format cannot adequately provide the capacity requirements for HDTV, which has led to the development of new standards for DTT.

4. Methods for increasing the multiplex capacity

There are several ways of increasing the capacity of a multiplex in order to accommodate more services. This section considers two important ways; using new technologies and the use of statistical multiplexing.

4.1. New technologies

4.1.1. MPEG compression

The bitrate needed to encode a single television programme very much depends on the type of picture compression technique used. The older MPEG-2 compression technique is currently used for SDTV in most European countries, although the codec technology has reached its peak.

The newer MPEG-4 technique is an improved video and audio coding compression standard which is expected to operate at up to double the efficiency of the MPEG-2 coding standard. There is also hope that MPEG-4 will experience improvements in the next ten years, although it might not be as dramatic as that experienced by MPEG-2. In Europe, it is expected that HD/DTT services will use the video compression standard MPEG-4/AVC (an ETSI Standard).

4.1.2. DVB-T2

DVB-T2 is the second-generation digital terrestrial broadcast technology. It promises an increase in efficiency of at least 40% in its use of terrestrial spectrum compared to DVB-T. It also has several options such as the number of carriers used, the guard interval (GI) sizes and the pilot signals, so that overheads can be minimized for any given transmission channel.

According to an estimate given by Ofcom in the UK [11], the introduction of DVB-T2 and MPEG-4 could, if combined, increase the service capacity by up to 160% for fixed reception. However, other experts consider 100% to be a more realistic estimation. The additional capacity provided can then be used for HDTV services.

4.2. Statistical multiplexing

The use of statistical multiplexing is another way of increasing the multiplex capacity. In a constant bitrate system, each video service in the multiplex has a fixed allocation of data rate, regardless of the content.

However, statistical multiplexing is based on the assumption that all programmes contained in the same multiplex will not consist of crucial scenes at precisely the same time. Therefore, it is expected that an intelligent multiplexer will use the output data rate of the encoders so that the one whose programme momentarily makes the highest demands on the MPEG coding process is always instantaneously allowed the highest output data rate.

The improved coding efficiency, due to sharing the multiplex capacity, increases with the number of channels, because the peaks and troughs of the bitrate demand across the channel average each other out better. *Fig. 1* shows the typical benefits that can be expected [12]. It can be seen from the figure that the percentage gain in efficiency becomes constant with a very high number of programmes in the multiplex.

Unfortunately there is a non-technical issue with statistical multiplexing, caused by competition between the programme providers. It might be difficult to accommodate the programmes from competing providers in one multiplex that applies statistical multiplexing, since in many cases the programme providers will insist on a guaranteed (and therefore probably fixed) data rate for their own programmes – which contradicts, to some extent, the principle of statistical multiplexing. Therefore, it seems desirable to have the programmes of just one programme provider in such a multiplex.

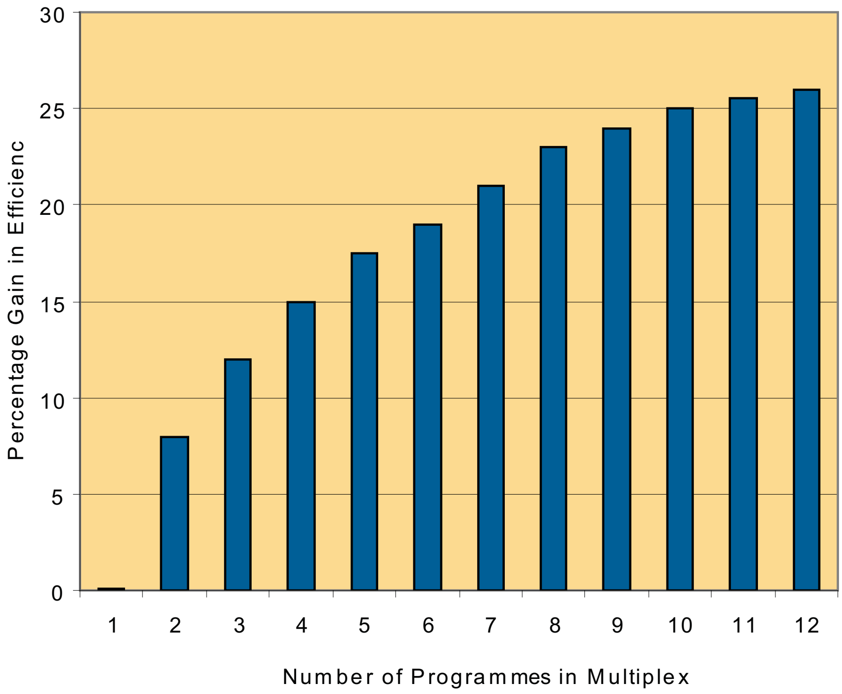

Figure 1
Efficiency gain of statistical multiplexing

5. Strategies for multiplex use

This section compares the multiplex capacity needed when combining the technologies described above. Presently, SD programmes are using MPEG-2 coding technology.

Table 2 gives the saving in capacity that is possible by switching SD services from MPEG-2 to MPEG-4. This could reduce the capacity used for television services by 30% to 40%.

It also shows the capacity needed to transmit HD services using MPEG-4. The HD 720p system has a smaller resolution than 1080i, so it requires a lesser multiplex capacity ... and a lower bitrate than interlaced scanning for the same picture quality. An increase of about 10 to 20 percent in transmission capacity is needed for 1080i, depending on the content type [8].

Although the video signal takes the majority of the available bitrate, there are some other data that are needed to be transmitted alongside. These include [9]:

- sound 0.2 to 0.5 Mbit/s *(0.2 Mbit/s used in Table 2)*;
- Service Information (SI) 0.1 to 0.3 Mbit/s *(0.15 Mbit/s used in Table 2)*;

Table 2
Required data rate for one programme, for different formats and source coding [13]

		Today			Expected in the Future		
Format	**Source coding**	**Required video data rate (Mbit/s)**	**Programme Associated Data (Mbit/s)**	**Total (Mbit/s)**	**Required video data rate (Mbit/s)**	**Programme Associated Data (Mbit/s)**	**Total (Mbit/s)**
SD	**MPEG-2**	3.00	0.55	3.55	3.00	0.55	3.55
SD	**MPEG-4/AVC**	2.10	0.55	2.65	1.79	0.55	2.34
HD-720p	**MPEG-4/AVC**	7.50	0.55	8.05	6.84	0.55	7.39
HD-1080i	**MPEG-4/AVC**	8.25	0.55	8.80	7.48	0.55	8.03

- Interactivity 0.1 to 1.0 Mbit/s *(0.1 Mbit/s used in Table 2)*;
- Subtitles/audio description 0.1 Mbit/s.

All of the above are regarded as programme associated data in *Table 2*.

The figures given in *Table 2* should be regarded as minimum requirements. Since broadcasters are allowed some trade-off in the video quality levels applied to programmes, the table shows the lower bounds which broadcasters must not go below. It is possible to have better-quality programmes with higher data rates for video and this means that the number of programmes in a multiplex would be reduced.

MPEG-4 encoding will improve over time as we have seen in MPEG-2. Ofcom in the UK has predicted the future multiplex capacity and use, by using past MPEG-2 improvements as a baseline [12]. It is predicted that MPEG-4 will improve by a factor of between two (worst case) and three (best case) over ten years. However, this prediction was based on the first set of encoders. This article's prediction is based on the state-of-the-art encoders presently available which do not give so much increase. A gain of 15% has been used for future predictions in *Table 2*.

Table 3
DVB-T and DVB-T2: C/N and data rate [14], [15], [16].

DVB-T					DVB-T2				
		C/N (dB)	Useful data rate (Mbit/s)				C/N (dB)	Useful data rate (Mbit/s)	
Modulation	Code rate	Rayleigh channel	GI = 1/4 (8K)	GI = 1/32 (8K)	Modulation	Code rate	Rayleigh channel	GI = 1/8 (16K)	GI = 1/32 (16K)
QPSK	1/2	5.4	5.0	6.0	QPSK	1/2	1.8	6.2	6.8
QPSK	2/3	8.4	6.6	8.0	QPSK	2/3	4.6	8.3	9.1
QPSK	3/4	10.7	7.5	9.1	QPSK	3/4	5.9	9.4	10.2
QPSK	5/6	13.1	8.3	10.1	QPSK	5/6	7.2	10.4	11.4
16-QAM	1/2	11.2	10.0	12.1	16-QAM	1/2	7.3	12.5	13.6
16-QAM	2/3	14.2	13.3	16.1	16-QAM	2/3	10.5	16.7	18.2
16-QAM	3/4	16.7	14.9	18.1	16-QAM	3/4	12.2	18.8	20.5
16-QAM	5/6	19.3	16.6	20.1	16-QAM	5/6	14.4	20.9	22.8
64-QAM	1/2	16.0	14.9	18.1	64-QAM	1/2	11.7	18.7	20.4
64-QAM	2/3	19.3	19.9	24.1	64-QAM	2/3	15.4	25.0	27.9
64-QAM	3/4	21.7	22.4	27.1	64-QAM	3/4	17.5	28.2	30.7
64-QAM	5/6	25.3	24.9	30.2	64-QAM	5/6	19.9	31.3	34.1
256-QAM	1/2	-	-	-	256-QAM	1/2	15.4	25.0	27.3
256-QAM	2/3	-	-	-	256-QAM	2/3	20.0	33.4	36.5
256-QAM	3/4	-	-	-	256-QAM	3/4	22.5	37.6	41.0
256-QAM	5/6	-	-	-	256-QAM	5/6	25.3	41.9	45.6

Table 3 shows the effect of switching transmission from DVB-T to DVB-T2. DVB-T2 offers a much richer choice of possible variants than DVB-T, regarding the modulation scheme, FFT mode, code rate, guard interval, etc. Not all of these possibilities are reflected in *Table 3*; rather a selection of most probable variants is given. The table shows that for a given sensitivity of the variant, i.e. for the same C/N value, a gain of more than 50% in useful data rate is achieved when going from DVB-T to DVB-T2. Similarly, for a given useful data rate, a gain of about 7 dB in ruggedness is achieved.

The C/N figures given are from the DVB-T and DVB-T2 specifications [14], [15]. In practice, the figures are about 3 dB higher for both DVB-T and DVB-T2. However, this leaves the conclusions of this article unchanged since they are based on the relative comparison of the two transmission systems.

As an example, the DVB-T variant 64-QAM-2/3-8K-GI 1/32 is used in many cases at present for fixed rooftop reception, providing a useful data rate of 24.1 Mbit/s. Similarly, for portable and mobile reception, quite often the variant 16-QAM-2/3-8K-GI ¼ is used with a useful data rate of 13.3 Mbit/s. DVB-T2 variants with a similar sensitivity would be 256-QAM-2/3-16K-GI 1/32 for fixed reception and 16-QAM-5/6-16K-GI 1/8 for portable reception. These are highlighted in green and red in the table. The particular benefit of such a choice for the DVB-T2 variants is explained in more detail in the next section. The useful data rates increase by 51% and 57%, respectively.

As discussed in *Section 4.2*, the application of statistical multiplexing provides further means to optimize the spectrum usage. This technique is already applied at present in MPEG-2/DVB-T multiplexes and should of course also be applied in the future where possible. The exact efficiency gain by using statistical multiplexing is dependent on both the type of video content, the details of implementation and also the number of channels in the multiplex. *Fig. 1* is used as a basis for the calculation of the statistical multiplex gain.

In order to assess the number of programmes that can be made available with a given amount of spectrum – or, the other way round, to assess the amount of spectrum required to provide a certain number of programmes – it is necessary to choose certain variants with definite values of the multiplex capacity. In this article, the above highlighted DVB-T/DVB-T2 variants are chosen as representative examples for fixed and portable/mobile reception, respectively.

Some time-critical data services, such as subtitles, have a variable data rate [12], so they can be included in a statistically multiplexed group as a high priority service rather than assigning a fixed data rate. This however, has a very minimal effect. The sound, subtitling and audio description are not expected to change very much and do not benefit from statistical multiplexing.

Table 4 for fixed reception and *Table 5* for portable/mobile reception give the relevant figures for the number of programmes that can be accommodated in a multiplex operated with the above

Abbreviations

16-QAM 16-state Quadrature Amplitude Modulation

64-QAM 64-state Quadrature Amplitude Modulation

256-QAM 256-state Quadrature Amplitude Modulation

720p High-definition progressively-scanned TV format of 1280 x 720 pixels

1080i High-definition interlaced TV format of 1920 x 1080 pixels

1080p High-definition progressively-scanned TV format of 1920 x 1080 pixels

AVC (MPEG-4) Advanced Video Coding, part 10 (aka H.264)

C/N Carrier-to-Noise ratio

CEPT *Conférence Européenne des Postes et Télécommunications* (European Conference of Postal and Telecommunications Administrations) http://www.cept.org/

DSO Digital Switchover

DTT Digital Terrestrial Television

DVB Digital Video Broadcasting http://www.dvb.org/

DVB-T DVB - Terrestrial

DVB-T2 DVB - Terrestrial, version 2

ETSI European Telecommunication Standards Institute http://pda.etsi.org/pda/queryform.asp

FEC Forward Error Correction

GE06 Geneva Frequency Plan of 2006

GI Guard Interval

ITU International Telecommunication Union http://www.itu.int

MFN Multi-Frequency Network

MPEG Moving Picture Experts Group http://www.chiariglione.org/mpeg/

MUX Multiplex

QPSK Quadrature (Quaternary) Phase-Shift Keying

RN Reference Network

RPC Reference Planning Configuration

SFN Single-Frequency Network

UHF Ultra High Frequency

VHF Very High Frequency

WRC (ITU) World Radiocommunication Conference discussed DVB-T/DVB-T2 variants, when statistical multiplexing is applied. For comparison, the figures for fixed multiplexing are also given.

Note that the exact figures for the number of programmes under fixed multiplexing were used for determining the number of programmes possible under statistical multiplexing.

In the fixed reception case, for example, for SDTV using MPEG-4 and DVB-T we can have ten programmes. This means that from *Fig. 1*, we can have 25% gain using statistical multiplexing

Table 4
Number of programmes per multiplex for fixed reception with DVB-T 64-QAM-2/3-8K-GI 1/32 and DVB-T2-256-QAM-2/3-16K-GI 1/32

Format	Source coding	No of progs DVB-T	No of progs DVB-T2	No of progs DVB-T	No of progs DVB-T2
		Fixed MUXing		Fixed MUXing FUTURE	
SD	MPEG-2	6	10	6	10
SD	MPEG-4/AVC	9	13	10	15
HD-720p	MPEG-4/AVC	3	4	3	5
HD-1080i	MPEG-4/AVC	2	4	3	4
		Statistical MUXing		Statistical MUXing FUTURE	
SD	MPEG-2	8	13	8	13
SD	MPEG-4/AVC	11	16	13	19
HD-720p	MPEG-4/AVC	3	5	3	5
HD-1080i	MPEG-4/AVC	3	4	3	5

Table 5
Number of programmes per multiplex for portable/mobile reception with DVB-T 16-QAM-2/3-8K-GI 1/4 and DVB-T2-16-QAM-5/6-16K-GI 1/8

Format	Source coding	No of progs DVB-T	No of progs DVB-T2	No of progs DVB-T	No of progs DVB-T2
		Fixed MUXing		Fixed MUXing FUTURE	
SD	MPEG-2	3	6	3	6
SD	MPEG-4/AVC	5	8	5	9
HD-720p	MPEG-4/AVC	1	2	1	2
HD-1080i	MPEG-4/AVC	1	2	1	2
		Statistical MUXing		Statistical MUXing FUTURE	
SD	MPEG-2	4	7	4	7
SD	MPEG-4/AVC	6	9	6	11
HD-720p	MPEG-4/AVC	1	2	1	3
HD-1080i	MPEG-4/AVC	1	2	1	3

which gives us twelve programmes with DVB-T. It is important to note that the following approximation has been used to round up figures for the number of programmes for DVB-T and DVB-T2:

$$0 – 0.84 \approx 0, \text{ and}$$
$$0.85 – 0.99 \approx 1$$

reflecting the fact that there is some freedom for the broadcaster to choose the data rate for a programme, and the DVB-T2 variant to be applied.

In general, a comparison of the various aspects described in *Tables 4* and *5* shows that the following trends can be expected with regard to the number of programmes that can be accommodated in one multiplex:

Going from MPEG-2 to MPEG-4:	Gain between 30% and 60%;
Going from DVB-T to DVB-T2:	Gain between 50% and 100%;
Going from fixed to statistical multiplexing:	0 programmes, if only a few programmes in the multiplex; 1 – 2 programmes, if four or more programmes in the multiplex;
Expected gain by future developments:	1 programme in most cases;
Difference between multiplexes for fixed and portable/mobile reception:	About 70% to 100%.

Applied, as an example, to the scenarios in France and Germany described in *Section 2*, the following conclusions can be drawn:

- The multiplex R5 in France, which uses the MPEG-4 coding technique to carry three HD programmes, already exhausts the predicted capacity available for DVB-T. For the other multiplexes, when MPEG-4 is applied, the number of SD programmes could be doubled from the current 5 to 7 programmes to between 11 and 13 programmes per multiplex. With the use of DVB-T2 an additional increase of about 50% could be achieved.
- In Germany, where the multiplexes can only accommodate 4 SDTV programmes at present, the use of both MPEG-4 and statistical multiplexing with DVB-T can increase the number of programmes up to 6 SDTV or 1 HDTV depending on the quality. With DVB-T2, it is possible to have up to 11 SDTV or 3 HDTV programmes depending on the quality.

6. Implementation of future DTT applications

6.1. The Framework of DTT implementations: the GE06 Agreement

6.1.1. Available spectrum

In order to exploit the full potential of DTT for future broadcasting applications, the available spectrum is to be used in an optimal way. In 2006, the ITU GE06 Agreement was established to introduce DTT in parts of regions 1 and 3 in Band III (174 – 230 MHz) and Band IV/V (470 – 862 MHz).

However, not this entire spectrum is exclusively reserved for DTT. Part or all of Band III is planned for digital audio / digital multimedia broadcasting in several countries and, in the meantime, in most of the CEPT countries the 800 MHz Band (790 – 862 MHz) is foreseen for mobile services, based on the WRC-07 allocation. *Fig. 2* gives an overview of the relevant spectrum and the present situation.

Since the amount of available spectrum is a crucial aspect for the assessment of the potential of DTT, a distinction is made in the considerations of this investigation according to the following aspects:

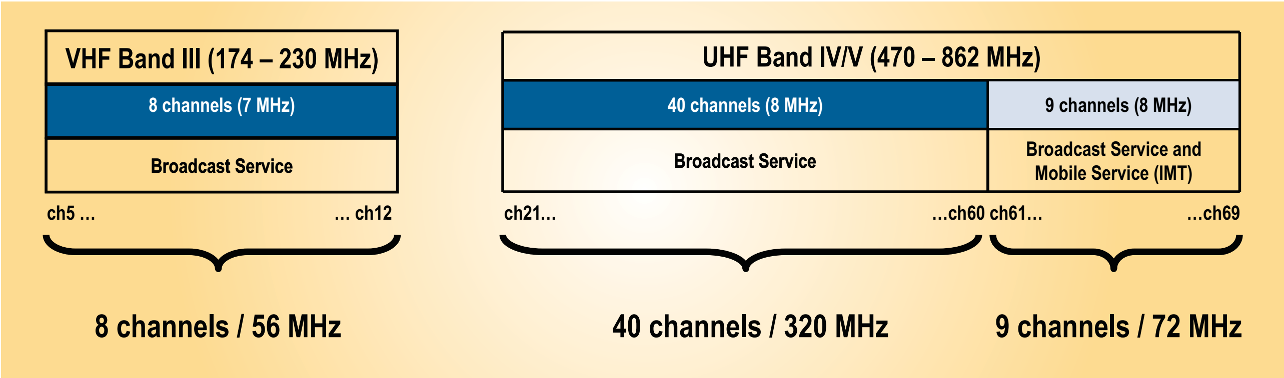

Figure 2
Spectrum for digital terrestrial broadcasting services in the GE06 Agreement

- only the core Band IV/V (470 – 790 MHz) is available to DTT;
- the full Band IV/V (470 – 862 MHz) is available to DTT;
- in Band III a certain amount of spectrum might be available for DTT.

All of the four possible combinations will result in a different amount of programmes that can be made available to viewers.

6.1.2. Network implementations

In principle, DTT allows for a large variety of system variants, different reception modes and network structures to be implemented, in order to fulfill the envisaged coverage. In the GE06 Agreement, a classification of these implementation options was established, described in terms of so-called Reference Planning Configurations (RPCs) and Reference Networks (RNs).

RPCs give the basic technical characteristics for the three reception modes: fixed, mobile/portable outdoor and portable indoor reception. The key parameter is the sensitivity of the transmission system, expressed as a C/N value. For example, portable indoor reception requires a more rugged variant than fixed reception, that is, its C/N value is lower than that for fixed reception.

RNs give the various power classes of the transmitters of a network implementation. Although in the first place intended for the description of Single Frequency Networks (SFNs), these reference networks also give an impression of the required transmitter power in Multiple Frequency Networks (MFNs).

Tables 6 and *7* give an overview of the RPCs and RNs. The transmitter powers in *Table 7* vary according to the intended reception mode.

Table 6
Reference Planning Configurations of the GE06 Agreement

Reference Planning Configuration	Reception mode	Reference C/N [dB]
RPC1	Fixed	21
RPC2	Portable outdoor mobile Portable indoor (lower quality)	19
RPC3	Portable indoor (higher quality)	17

Most plan entries of GE06 are based on or resemble these reference planning configurations and the technical characteristics of the reference networks. Therefore, to conform to a GE06 plan entry, a

Table 7
Reference Networks of the GE06 Agreement

Reference Network	Number of transmitters in RN	Type	Transmitter power (at 650 MHz)
RN1	7	Large service area	19.0 – 174 kW
RN2	3	Small service area	1.5 – 42.7 kW
RN3	3	Small service area (urban environment)	1.5 – 166 kW
RN4	3	Small service area (semi-closed = power restricted)	0.9 – 30.2 kW

DVB-T2 variant should be chosen that fulfills the coverage intention when operated with, at most, the maximum allowed transmitter power of the plan entry. When the same coverage as for the original DVB-T implementation is intended, in addition, a DVB-T2 variant should be chosen that has a C/N value similar to the former DVB-T plan entry. This is the reason why in *section 5* DVB-T2 variants were chosen as a reference with C/N values similar to typical DVB-T implementations.

Fig. 3 gives an overview of the reception modes in Europe as recorded in the GE06 Plan.

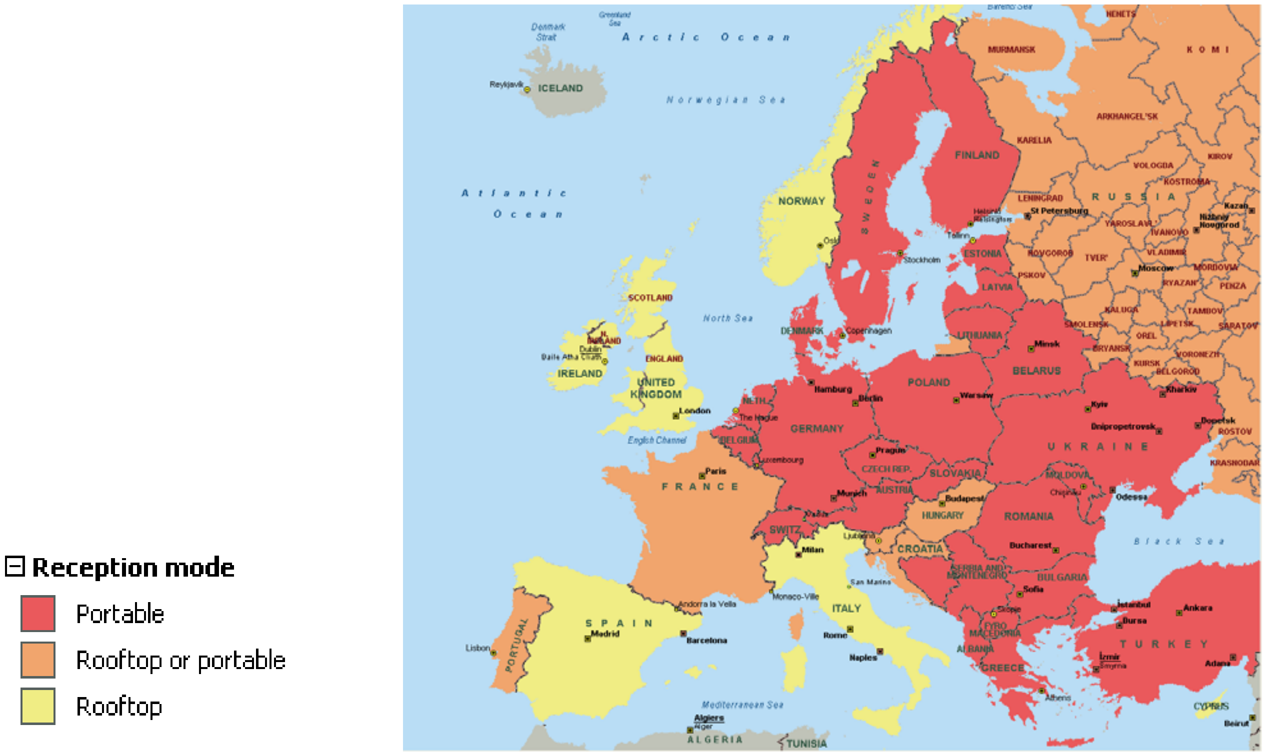

Figure 3
Reception Modes as recorded in the GE06 Plan (taken from [3])

6.1.3. The Layer Concept

In Europe, for the establishment of the GE06 Plan, a layer concept was applied. A layer is a set of frequency channels distributed across the planning areas such that each location of the planning area, where reception is intended, is covered with one multiplex. This coverage could be full area or partial. In general, six to eight channels are needed for one full area coverage. The actual requirement for a specific planning area will depend on several aspects:

- size and shape of the intended service areas;

- applied network structure;
- intended coverage concept.

In order to assess the capacity that is available for the provision of terrestrial HDTV, in this article it is assumed that a homogeneous full-area coverage of a country or planning area is intended, and that for a layer, seven channels are needed. Of course, this scenario can only give an indication of the available capacity. Individual scenarios may differ from country to country; however, certain trade-offs have to be kept in mind. Several categories of trade-off exist which may modify the figures and conclusions of the present investigation *(see Table 8)*.

Table 8
Trade-offs for various categories of DTT planning considerations

Category	Trade-off
Full area vs. partial coverage	Larger vs. smaller amount of channels needed for one layer
Higher vs. lower quality of picture and associated data	Smaller vs. higher number of programmes per multiplex
Fixed vs. portable/mobile reception	Higher vs. smaller available data rate per multiplex
MFN vs. SFN approach	Higher vs. smaller data capacity per multiplex and Larger vs. smaller amount of channels per layer

According to these considerations *Table 9* gives the number of available layers for DTT.

Table 9
Number of layers

Band	Range	Number of Layers
Core Band IV/V	470 – 790 MHz = 40 channels (8 MHz)	~ 6 layers
Full Band IV/V	470 – 862 MHz = 49 channels (8 MHz)	~ 7 layers
Band III	174 – 230 MHz = 8(7) channels (7(8) MHz)	~ 1 layer

6.2. Number of available programmes

Now, according to the findings in *sections 5* and *6.1*, the number of programmes can be evaluated that may be provided with the available spectrum in SD and HD service quality and the different reception modes. The numbers will be calculated on the basis of the figures assessed for future possibilities to accommodate programmes in a multiplex applying statistical multiplexing as described in *Table 5*.

Three scenarios of available spectrum are considered: Core UHF band, full UHF band and, in addition, the VHF band.

Apart from the provision of high-quality broadcasting services (in SD or HD resolution), mobile broadcast services with a low resolution, requiring only a few hundred kbit/s may also be accommodated in the considered spectrum. Possible scenarios are summarized in *Table 10*.

Table 10
Possible scenarios for different availability of spectrum

Available spectrum for SD/HD DTT and Mobile TV	Possible scenarios		
Core UHF	6 SD/HD layers	5 SD/HD layers + 1 mobile TV layer	-
Full UHF or Core UHF + 1 Layer in VHF	7 SD/HD layers	6 SD/HD layers + 1 mobile TV layer	5 SD/HD layers + 2 mobile TV layers
Full UHF + 1 Layer in VHF	8 SD/HD layers	7 SD/HD layers + 1 mobile TV layer	6 SD/HD layers + 2 mobile TV layers
Core UHF = 470 – 790 MHz, Full UHF = 470 – 862 MHz, VHF = 174 – 230 MHz			

As a conclusion, 5 to 8 layers for SD/HD broadcasting services seem to be possible. For this range of possibilities, *Table 11* gives the number of programmes that may be made available in SD and HD quality on the one hand, and fixed and portable reception on the other hand, respectively.

Table 11
Number of available programmes for different picture quality, reception modes and the amount of available layers

Number of available layers for SD/HD DTT	Fixed reception		Portable/mobile reception	
	SD Quality	HD Quality	SD Quality	HD Quality
5	95	25	55	15
6	114	30	66	18
7	133	35	77	21
8	152	40	88	24

Table 11 shows that a very high number of programmes can be made available in SD quality when MPEG-4 and DVB-T2 techniques are applied, be it for 5 or 8 layers, or for fixed or portable reception. However, since it can be expected that HD will be the future quality standard for DTT, a much lower number of available programmes is to be expected.

In general, it is assumed that an offer of at least 20 – 25 programmes is required to provide a competitive broadcast platform. That means that all considered spectrum scenarios provide satisfactory resources to give a minimum amount of HD programmes for fixed reception; however, for portable reception, at least 7 layers would be required.

Scenarios and figures with similar findings were discussed earlier in an EBU investigation [17].

These conclusions are based on the chosen reference assumption of a homogeneous full-area coverage of the planning area. As indicated earlier, this assumption may not be valid for all countries, implying a modification of the number of programmes available at a given location. Some countries may choose a non-homogeneous area coverage with a higher number of multiplexes in metropolitan areas and a lower number in rural areas; other countries may choose a non-homogeneous distribution of the coverage quality resulting in a higher overall number of available programmes, etc.

Moreover, *Table 5* only provides the figures for an exclusive use of a multiplex for either HD programmes or SD programmes. But DVB-T2 also allows for the mixed combination of HD and SD programmes in one multiplex, according to the preferences of the broadcaster(s) represented in the multiplex. A large number of combinations of HD and SD programmes are possible.

6.3. Alternative scenarios

In the previous sections the higher efficiency of MPEG-4 and DVB-T2 has been exploited to provide a higher data capacity for existing GE06 plan entries. But this higher efficiency may also be used within the framework of the GE06 Plan to establish alternative scenarios; however, these would be accompanied with sometimes less, sometimes more, additional re-planning effort. Some of these alternatives will be sketched in this section.

An alternative scenario is the extension of the coverage area of a given plan entry (assignment or allotment) while keeping the original data capacity of the plan entry. This scenario does not necessarily imply any additional coordination. But broadcasters and/or administrations have to check whether this fits into their future plans for broadcasting, since the original GE06 planning did not take account of such possible extensions whose benefits might therefore turn out accidentally.

In a similar way, a given plan entry that was originally designed for fixed reception could be upgraded to portable/mobile reception while approximately keeping the original data rate and coverage area. Again, in general, this does not necessarily imply any additional extensive coordination requirements.

DVB-T2 allows for an improved application of the SFN concept. If this is done on a medium scale, i.e. used to establish local or regional SFNs, this might be possible with a moderate amount of national and international coordination effort. The benefit could be a more efficient use of the spectrum but, in most cases, being accompanied with a costly major network restructuring.

If the full potential of DVB-T2 to create SFNs, i.e. on a national scale, were to be exploited, a more or less total re-organization of the GE06 Plan would be necessary along again with a major network restructuring.

6.4. Transition phase

A further relevant aspect of the implementation of advanced source and transmission coding techniques to achieve a higher spectral efficiency is the question of the transition from established techniques to the new ones. Although not the subject of this article, some short considerations on this issue may be noted.

Broadcasters have gained rich experience with such a transition when moving from analogue to digital transmissions, and in many countries they are still in this phase. Some of the lessons learned are:

- the higher the percentage of viewers that depend on the terrestrial platform as compared to other platforms, the more difficult and lengthy is the transition period;
- for a certain period, a simulcast of programmes with old and new techniques is required;
- a certain amount of additional spectrum is needed for this, to accomplish the transition to new and more efficient techniques;
- an incentive is required for viewers to accept the transition to new techniques because it may imply an upgrade of the user equipment, which they will have to pay for.

In addition, the challenges broadcasters are faced with during the transition to MPEG-4 and DVB-T2 will vary from country to country. Some countries are at present still in the transition phase from analogue to digital; they might think of an immediate move to MPEG-4 coding. Other countries – in particular in non-CEPT countries for example in Africa – might think of an immediate move from analogue transmissions to MPEG-4 / DVB-T2 in a few years when also DVB-T2 will become generally available. Countries that have established DTT but still simulcast analogue transmissions might use their ceasing of analogue transmissions to introduce MPEG-4 / DVB-T2 for part of their broadcast offer. Others that have already accomplished the full transition to DTT with MPEG-2 / DVB-T will hesitate to quickly adopt MPEG-4 and/or DVB-T2 since viewers would be urged to replace their recently acquired receiving equipment, etc. The listing shows that no generally valid approach seems to be applicable.

7. Conclusions

This article has investigated the potential of digital terrestrial television to provide a competitive platform for future broadcasting applications. High definition TV (HD) is assumed as a future standard for all TV applications. The number of programmes that can be accommodated in a multiplex when applying new source coding techniques (MPEG-4) and new channel coding techniques (DVB-T2) have been assessed and the possibilities available within the GE06 Agreement have been discussed.

The investigation shows that, with the introduction of MPEG-4 plus DVB-T2, it is possible to provide a competitive offer on the terrestrial platform within the framework of the GE06 agreement. This is certainly true for fixed reception while, for portable / mobile reception, at least 7 layers seem to be required to achieve this goal.

Furthermore, the conclusion can be drawn that broadcasters only benefit from a transition to MPEG-4 and/or DVB-T2 under the assumption that this application of more frequency-efficient techniques can be used by them for an improved programme offer in terms of higher quality (HD) and/or a larger number of programmes.

For these reasons it is indispensible that the presently-available broadcasting spectrum remains available for broadcasting. Further reducing the broadcasting spectrum would seriously jeopardize the competitiveness of the DTT platform.

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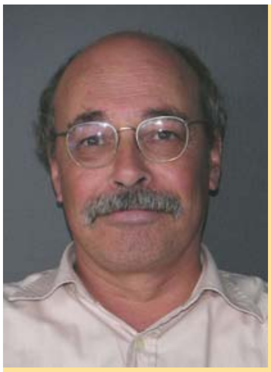

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Some relevant web sites

German regulator BNetzA: **http://www.bundesnetzagentur.de**

French regulator CSA: **http://www.csa.fr**

UK regulator Ofcom: **http://www.ofcom.org.uk**

DigiTAG: **http://www.digitag.org**

DVB: **http://www.dvb.org**

EBU TECHNICAL: **http://tech.ebu.ch/**

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