3DTV Roll-Out Scenarios: A DVB-T2 Approach

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***Abstract*—This paper presents an analysis of the characteristics of the DVB-T2 standard to deliver 3DTV contents (3DTV). The work has been based on the current state-of-the-art developments in technologies that enable 3DTV delivery, from production to displays, with special emphasis on formats and coding efficiencies. Based on bitrate and format requirements the capacity of DVB-T2 is investigated, proposing two roll-out scenarios and discussing the associated DVB-T2 configuration parameters. The target receivers are both fixed and portable, and different backward compatibility problems and solutions are highlighted. The result of this work is an estimation of the number and type of services (both 2D and 3D) that this standard will be able to deliver in the mid term future as 2D HD and 3D services become commercially available.**

***Index Terms*—DVB-T2, network planning, terrestrial broadcasting, 3D television.**

I. Introduction

DB-T2 is the next generation standard for terrestrial delivery produced by the DVB (Digital Video Broadcasting) consortium. The standard was approved in 2009 by the ETSI (European Telecommunication Standards Institute) [1]. The standard was originated by the demands to increase the spectral efficiency of digital terrestrial broadcast systems in the VHF/UHF bands. The increase in bitrates required mainly by HDTV content was behind this demand, but it will also serve other future services such as 3DTV.

The standard provides a remarkable flexibility in multiplex allocation, coding, modulation and RF parameters. This flexibility allows bitrates that range from a few Mbps to 50 Mbps depending on the robustness vs. throughput compromise. This flexibility is achieved at the expense of a significant complexity. The number of possible system parameter combinations has grown exponentially if compared with its terrestrial predecessors (DVB-T, DVB-H) [2]–[4].

The objective of this paper is to analyse the feasibility of the DVB-T2 standard to deliver a mixture of HDTV (2D) and 3D services as a function of different system configurations. The work has elaborated a set of assumed roll-out criteria and proposes a methodology to select the most appropriate DVB-T2 modes. The work has considered two possible scenarios that could be deployed at different times in the mid term future: a transition period, with HD and 3D services coexisting followed by a second case, where 3D technology will be more mature and rich 3D content will be delivered to the consumers. Recent releases from the DVB consortium are in line with this assumption [5].

The paper is organized as follows. Section II presents a short description of current developments along the 3D delivery chain. The aim of this section is to provide a quick overview to readers aware of DVB-T2 developments for SD and HD applications but not familiar with 3D systems. Section III highlights the relevant aspects of the DVB-T2 standard that will be used in the analysis presented in further sections. Section IV describes the 3D image formats used in the analysis. Section V follows with a description of the proposed scenarios, describing compatibility specifications, assumed HD and 3D coding bitrates. Finally, Section VI presents the conclusions of the work.

II. Three-dimensional TV Enabling Technologies

This section provides an overview of some of the 3DTV enabling technologies that could match the requirements of a terrestrial broadcasting system. The emphasis in the following paragraphs is put on production-coding and reception-presentation terminations. These will determine the major restrictions and requirements for the distribution and transmission standards to deliver 3D content. The requirements will be closely related to the coding efficiency, required bitrates, Quality of Service (or experience) and receiver scenarios (fixed, mobile, portable, etc). Other factors such as backwards compatibility with legacy 2D systems (HDTV) options cannot be left aside either.

A. Production

The first step in a 3D television chain is the generation of suitable content. The choice of possible technology formats will determine some of the constraints associated to the production methodologies. In the last years, a variety of 3D production techniques have been developed [6], [7].

Currently, different generation families can be considered: single camera 3D generation, two-camera systems and multi-camera systems. Other alternative techniques such as the so called "Time-of-Flight" cameras, which integrate image and scene depth information in real time [6] are under development nowadays.

Stereoscopic cameras are capable of generating 3D content in stereoscopic format. A complete TV system based on stereoscopic content capture can be found in [8].

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The Multi camera systems derived from telepresence and videoconference systems, require complex and precise synchronization and calibration procedures between a variable number of cameras [6].

An additional family of techniques is based on image depth maps. Intense research has been carried out involving Time-Of-Flight systems [9]. The scenes captured by these systems are based on the LDV (Layered Depth Video) and MVD (Multiview Plus Depth Video) formats. Several research projects in Europe ATTEST [10] and 3D4YOU [11], [12] are investigating production techniques that produce accurate content depth maps. These depth maps can be treated as an additional video component to sum up to the two dimensional video information

Additionally, other techniques based on N cameras are under study to enable a completely free viewpoint television experience [13].

B. Coding

The objective of coding will be to make both the bandwidth needed for transmission of the target stream and the computation complexity as low as possible while maintaining high resolution of the reference view [14]. Different 3D rendering systems and formats (stereoscopic, multiview, depth map) require different scene representation approaches and thus different coding techniques. In all cases, efficient coding will be a key for a global 3DTV system success [15].

The coding techniques for stereoscopic systems exploit the similarities between each pair of frames of a video sequence and also between frames along the sequence [15]. Some compression algorithms rely on an independent coding of one of the video components and a relative coding of the other component based on the same movement compensation concepts. Following this approach, some work has been done using MPEG-2 (MPEG-2 Multiview Profile), and H.264 [16], or MPEG-4 Visual [17]. Compression gain provided by these inter-view stereoscopic techniques is nevertheless limited because independent coding of each component has shown a similar performance [15].

One of the alternatives to the traditional stereoscopic formats is based on coding the video content plus an additional sample depth map [18]. This approach is very efficient from a compression perspective because sample depth data could be considered a monochromatic video component. The associated depth value to each pixel will be in the range of a maximum and minimum distances, and, therefore, can be coded as a gray scale conventional video signal [19]. Tests have been carried out with different codecs (MPEG-2, MPEG-4 and H.264/AVC). They conclude that a monochromatic depth information signal can be coded with a 10–20% of the bitrate required for a color video signal [20]. On the decoder side, the stereo signal is reconstructed by DIBR techniques (Depth-Image-Based Rendering) [19]. The complexity of these techniques is on the content creation side [15].

Finally, for multi view systems, the coding algorithms will remove the redundancies between the different views of the same scene. Multiview Video Coding (MVC) techniques combine time and inter-view coding. Prediction is carried out not only from temporally neighboring frames but also from simultaneous frames in adjacent views [15]. Some of the experiments carried out so far show that MVC exceeds the compression gain of an independent coding [21]. Nevertheless, the coding gain is highly dependent on the content and properties of the capturing system (distance between cameras, frame rate, scene complexity, etc). The extreme complexity of the time/inter-view prediction structure is a problem for efficient coding, though research is being carried out to simplify the algorithms while maintaining compression ratios [22].

Concluding the section dedicated to coding, it is clear that there is still a long way to improve both the stereoscopic and the multi view video formats [23], [24]. This paper will treat video coding from a general perspective, showing use cases by formats and coding families in order not to restrict the main conclusions of this work to the developments currently available at the time of writing the manuscript.

C. Reception

The terrestrial television reception infrastructure has not changed significantly in the past 20 years. In fact, all the commercial requirements prior to DTV standard developments in the nineties and the early 21st century [2]–[4] imposed compatibility conditions with existing analog antenna distribution systems for analog TV. In the following years, the situation is expected to remain similar. Changes in this field might be associated to a change in the frequency band attributions to the terrestrial Broadcasting Service. Nevertheless if the percentage of the population that uses the terrestrial propagation as the main receiving pipe is taken into account [25], the UHF (either partially or totally) will remain the terrestrial broadcasting band for television systems [26], [27].

The implications associated to the receiving systems in the latest version of standards will be associated to minimum carrier to noise requirements and coverage targets.

At the receiver side, it is worth mentioning the intensity of the work towards portable 3D developments carried out in countries like Korea [28], [29]. The first generation of portable receivers and displays based on T-DMB is already on a pre-commercial prototyping status. Again, the assumption is that the receiver performance remains similar to the performance of 2D portable receivers.

D. Presentation and Displays

Display is the last step in the 3DTV chain and to a great extent the key part for a widespread acceptance of the system by the consumers [30]. There are, as in production and coding, a diversity of techniques and proposals. A comprehensive classification can be found in [31]. This reference describes four categories: autostereoscopic systems, volumetric systems, holographic systems and systems based on "head-mounted displays".

Autostereoscopic techniques do not require any user-mounted device [31]. This family could also include volumetric and holographic systems. Nevertheless, the traditional use of this terminology is restricted to techniques reproducing 3D images within the viewing field [30], [31]. There are three subcategories of the autostereoscopic systems: binocular,

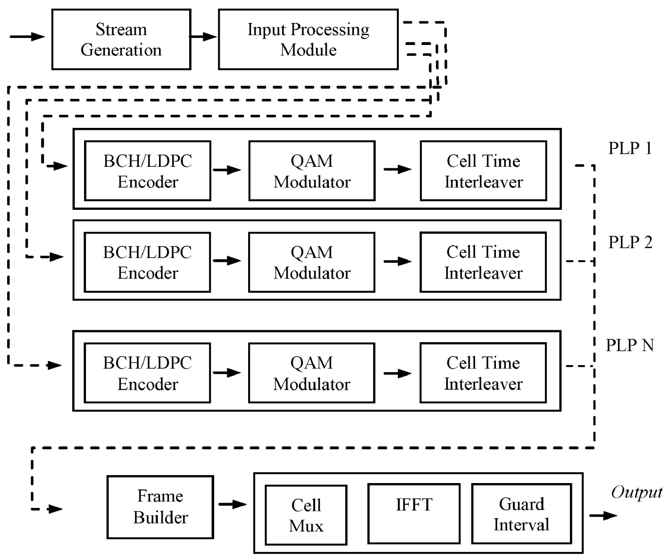


Fig. 1. DVB-T2 modulation block diagram.

multiview and holoforms. Binocular systems are the simplest approach, and generate 3D images in a fixed viewing zone [31]. Multiview systems have a discrete number of views within the viewing field, generating different regions where the different perspectives of the video scene can be appreciated. In this case, some motion parallax is provided but it is restricted by the restricted number of views available. Nevertheless, there are adjacent view fusion strategies that try to smooth the transition from a viewing position to the next ones [31]. Holoform techniques try to provide a smooth motion parallax for a viewer moving along the viewing field.

Volumetric displays are based on generating the image content inside a volume in space. These techniques are based on a visual representation of the scene in three dimensions [32]. One of the main difficulties associated to volumetric systems is the required high resolution of the source material.

Finally, holographic techniques aim at representing exact replicas of the scenes that cannot be differentiated from the original. These techniques try to capture the light field of the scene including all the associated physical light attributes, so the spectator eyes receive the same light conditions as the original scene. These techniques are still in a very preliminary study phase [33].

III. DVB-T2 Standard

This section highlights the most relevant aspects of the DVB-T2 standard. Fig. 1 shows a block diagram of the DVB-T2 signal generation process. The standard uses the latest advances in coding (LDPC) [1] and is based on OFDM techniques.

A. Input Formats and Streams

One of the main novelties of DVB-T2 is the possibility to transmit different streams of video, voice and data as independent streams with their own parameters, allowing a better system capacity allocation. DVB-T2 considers four potential input formats. Besides the traditional MPEG-TS container, the system offers three additional generic data formats with fixed or variable packet lengths: Generic Stream Encapsulation (GSE), Generic Continuous Stream (GCS), or Generic Fixed-length Packetized Stream (GFPS) [1]

B. Modulation and Coding

DVB-T2 uses OFDM (Orthogonal Frequency Division Multiplex) modulation. Larger FFT modes (16K, 32K) and the inclusion high order 256-QAM constellations increase the number of bits per symbol and in consequence the throughput of the system. This paper will make use of these features in order to match the capacity demands of 3D and HDTV content.

In the same way as DVB-S2 standard, DVB-T2 uses LDPC in combination with BCH codes improving the FEC modules. The specification makes also use of scattered pilot patterns where the number of patterns available has been increased providing higher flexibility and maximizing the data payload depending on the FFT size and Guard Interval adopted. This paper will propose a selection of modulation and FEC parameters based on the required bitrates and minimum carrier to noise ratios.

C. Physical Layer Pipes

The DVB-T2 physical layer data is divided into logical entities called the physical layer pipe (PLP), each PLP carrying one logical data stream each one with specific coding and modulation characteristics. The PLP architecture is designed to be flexible so that arbitrary adjustments to robustness and capacity can be easily done. Thanks to the PLP concept, different robustness modes can be selected for different services improving the system performance and flexibility. This feature has provided the tool to include applications targeting fixed and mobile services using the same RF channel, with an adequate configuration suite for each receiver type.

IV. Three-dimensional Formats for Terrestrial Broadcasting

This section describes the 3D content formats that have been considered for the present study. The starting point is the lack of a standard, or in its absence, a widely accepted format that could be the most used format in the mid term. Some of the tendencies have been outlined in Section II. All the options used in this work are either stereoscopic or autostereoscopic, and thus at the end display systems, left and right images will be necessary. Volumetric and holographic systems have not been considered. Under this assumption, three alternative formats will be presented as follows:. [5], [34]–[36].

— Frame Compatible 3D, also known as "3D in 2D"
— 2D + Enhancement Layer, also known as "2D+Delta"
— 3D + Enhancement Layer (following the nomenclature in the previous formats we could identify this format as) "3D in 2D + Enhancement"

All three options are based, in one way or another, on 2D HDTV image formats. Nevertheless, the compatibility of these formats with existing HDTV displays will be only possible with the second choice "2D+Delta", and even in this case, this compatibility will depend on how the different data streams associated to this format are presented to the receiver.

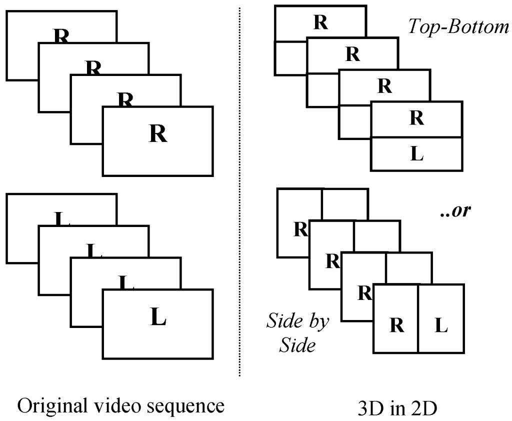


Fig. 2. Three-dimensional in 2D format.

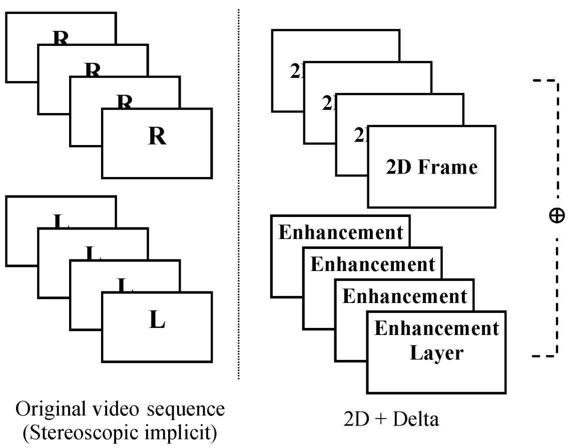


Fig. 3. Two-dimensional + Delta format.

A. Frame Compatible 3D

The well known idea behind this format is shown in Fig. 2. Stereoscopic video will be sent within the HDTV 2D image structure. Bearing in mind the number of pixels and frame rate of the HDTV 2D image, the embedded 3D content will be decimated and thus, this option will produce limited quality images.

Figure shows only two of the existing options (side-by-side, top-bottom).

This format is compatible with current set top boxes (DTV receivers) but would require a new display system to make it visible. In consequence, this format would produce images that cannot be represented (meaningfully) by a conventional HDTV display.

B. Two-Dimensional Plus Enhancement Layer

This format would represent the family of systems based on sample depth maps (See Section II). Fig. 3 shows a simplified representation of the concept behind this format. The interesting advantage of this format is related to compatibility with existing 2D displays.

C. Three-Dimensional in 2D Plus Enhancement Layer

This format represents the bridge between first generation 3D consumers that will receive content with limited resolution and advanced 3D full resolution receivers. In this case, the base layer is the content is the 3D in 2D format. An advanced receiver would also use the information of the enhancement layer to build a full resolution 3D picture. Fig. 4 shows the concept associated to this format.

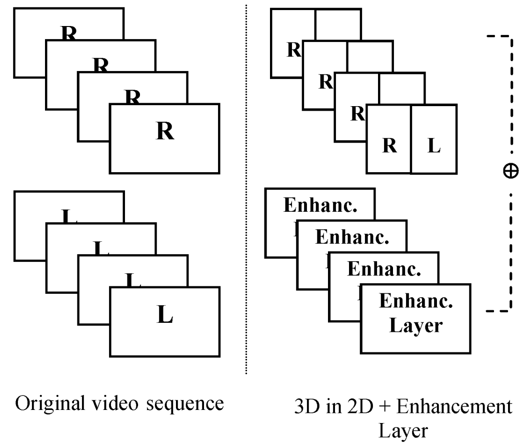


Fig. 4. Three-dimensional in 2D + enhancement layer.

Due to a high level of correlation, the enhancement layer bit-rate cost is substantially less than double the 3D-in-2D base layer image [36].

V. Service Scenarios

The lack of an accepted standard has been mentioned in the previous section. In addition, some of the basic technologies associated to a stable 3D solution for terrestrial broadcasting, including formats, display technologies and baseband coding are still a matter of discussion (and also technical improvements) in the broadcast community. This section tries to set up some boundary conditions to build the choice of roll out scenarios proposed in this paper. The boundary conditions are related to the target receivers (fixed, portable, mobile), backwards compatibility requirements with existing DVB-T2 receivers (simultaneous HDTV-3D services), content quality requirements (not only, but mostly bitrate allocation to each HDTV and 3D content), service coverage areas and minimum required field strength values. Additionally, and most probably the most relevant question would be the business model associated to the roll out scenario. The business models have been deliberately left aside in this paper. The authors have tried to develop the technical requirements, constraints, and basic architecture from a holistic perspective. Business models in the future, will decide which of the technical alternatives presented in this paper (if any) will be commercially successful.

A. Target Receivers

Two receiver types have been considered in a first roll out stage: fixed reception and portable outdoor reception. Mobile and indoor portable reception have been left for further deployment phases. In fact, the addition of portable outdoor reception has been included as the intermediate step prior to mobile and indoor reception, which will require a densification of the DVB-T2 infrastructure [37] or the addition of further capabilities (future DVB-NGH standard) [38].

TABLE I
HDTV MPEG-4/AVC CODING RATES

Modulation	Bitrate Max.	Bitrate Min.	Value used in this paper
720p	11	6	8
1080i	13	7.5	10
1080p	13	7.8	13

TABLE II
THREE-DIMENSIONAL CODING RATES FOR FIXED RECEPTION.(VALUES IN THE TABLE ARE BEING USED FOR CALCULATIONS IN THIS WORK)

Modulation	Bitrate Max.
3D in 2D	13
2D + Delta	15.6
3D in 2D + Enhancement	15.6

In the case of fixed reception, defined as the one with directional roof-top antennas, the target coverage areas in the first phase will be urban environments. At the receiver side, the existing infrastructure for fixed reception is assumed to remain unchanged for a while. Significant improvements in the household TV receiving systems (SMATV) or in the RF stages of mass market 3D set top boxes are not expected in the mid term, which again will influence the choice of the DVB-T2 mode, the C/N requirements and the coverage area.

Portable reception is considered as in [39] with non directional antennas at 1.5 meters at ground level. It is worth mentioning that portable 3D pre-commercial receivers are already available in countries like South Korea [28], [29].

B. Service Types and Bitrate Requirements

Three service types are considered in this study: 2D High Definition services, 3D services (full or half resolution) and 3D services for portable receivers.

There are three different possible formats for delivering HD content: 1080 × 720 progressive scanning (720p), 1920 × 1080 interlaced scanning (1080i), and 1920 × 1080 progressive scanning (1080p) [40], [41]. Currently, the first two options have been adopted or recommended by different countries and consortia. There have been exhaustive tests in the previous years in order to compare the subjective quality provided by each format for different contents and coding rates (MPEG-4/AVC and MPEG-2) [40], [41]. The 720p has provided better subjective performance for a given bitrate if compared to the 1080i (bitrates up to 18 Mbps).

Most studies conclude that the best performance is provided by the 1080p format, which at the same time will require, depending on the content type, a 30 to 50% more bitrate [40], [41]. In this study the coding algorithm used is MPEG-4/AVC for all cases presented.

Based on the references mentioned in above, and also considering the HDTV services currently on air (terrestrial delivery and cable/satellite) a summary of required bitrates are presented in Table I.

The coding output bitrate is still a matter of discussion [25], [42], [43]. Values from 6 to 18 Mbps can be found in different reports as a function of the perceptual quality and delivery infrastructure (terrestrial, cable and satellite). The values adopted in this work are a summary of the values found in these references, including the future performance gains forecasted by the same authors for the following 5 to7 years in the case of 1080p the coding algorithm is MPEG-4/AVC. The capacity calculations in next section will be carried out for a bitrate close to the maximum values that has been reduced considering expected gains in statistical multiplexing and advances in the coding technologies [43].

The advanced in the coding techniques are currently focused in two areas: Multiview Video Coding (MVC) targeting video coding for 3D applications [15] and Next Generation Video coders (also know as H.266 or H.NGVC) aiming at a 100% improvement in coding efficiency. In any case, the standardization of those coders will not come in the short term.

The bitrate requirements associated to 3D services will depend on the format choice as described in Sections II and IV and will be closely related to the MPEG-4/AVC coding efficiency of 2D images. In fact the base layer of the formats considered in this paper is always a modified 2D image ("3D in 2D") or a plain 2D frame ("2D+Delta"). Additionally, the enhancement layers associated to the formats "2D+Delta" and "3D in 2D + Enhancement" will depend on the bitrates provided by coding tools [36]. Table II shows the bitrates considered in this work.

In the case of portable receivers, the third option, "3D in 2D + Enhancement" has been discarded for obvious quality requirement differences associated to the reduction in display dimensions. Different bitrates for 3D portable services have been under study in Korea [44] and Europe [46] and proposals range from 512 Kbps to more than 1 Mbps, depending on the content and quality targets. This work will assume a stream of 0.75 Mbps per mobile service.

VI. STUDY CASES

This section presents two study cases designed to account for the possible 3D content deployment scenarios in future terrestrial networks. The objective is to provide a realistic approach (as much as possible considering the information available today) of the technical capabilities of the DVB-T2 standard considering compatibility aspects with existing HDTV receivers and current broadcast infrastructure.

A. Roll Out Criteria

The first condition is related to compatibility and prevalence of existing 2D services. At the moment of deploying 3D content in certain regions (countries), it is envisaged that HDTV will be the dominant content type. There are two ways of tackling the 3D roll out while maintaining the prevalence of HD (2D) services. The first approach would consist of creating mixed multiplexes, where HDTV and 3D content (see Fig. 5) are delivered by the same infrastructure (same DVB-T2 signal). The second approach would be based on separate RF signals. In this scenario, there would be some RF UHF channels dedicated to HD and some others to 3D. At this point, it is worth mentioning that the success of any or both options will depend strongly on the

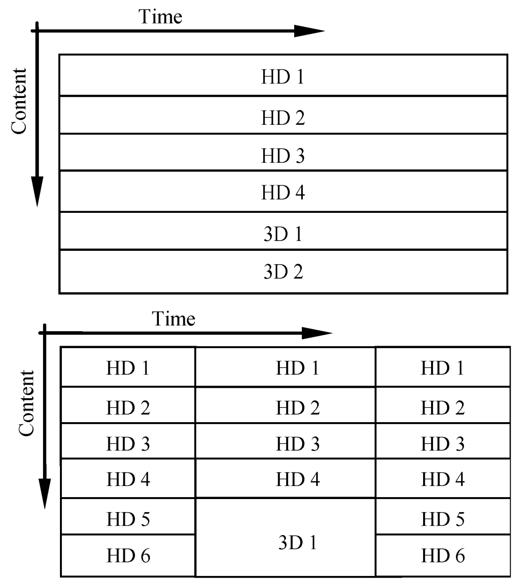


Fig. 5. Mixed HD-3D content: fixed and dynamic number of programs.

TABLE III
DVB-T2 MODES IN BACKWARDS COMPATIBILITY SCENARIO I (USE CASE: UK COMPATIBLE MODE 32K 1/128)

Modulation	LDPC Code Rate	BITRATE	Required C/N
64-QAM	4/5	36.08	16.4
64-QAM	5/6	37.62	17.2
256-QAM	3/5	36.14	16
256-QAM	2/3	40.21	17.8
256-QAM	3/4	45.24	20.2
256-QAM	4/5	48.27	21.5
256-QAM	5/6	50.32	22.3

business model and the spectrum policies at the region where these services would be set up.

Both scenarios account for a situation where current 2D standard definition (SD) services are not longer on air or at least, a situation where they are not the prevailing service. In any case, the methodology applied here would not change, as SD programs would be a particular case of HD 2D content. If this would be the case, the number of possible 2D programs, or the capacity left for 3D would obviously increase.

Another roll out criterion is related to spectrum planning. This work has supposed that the planning unit is an RF channel in the UHF band. Once this condition is assumed, the different service delivery choices are elaborated based on the flexibility of Physical Layer Pipes in DVB-T2. The standard has also an additional tool that provides further flexibility: the Future Extension Frames, if new multiplexing, channel coding or modulation techniques would be necessary (for example adding MIMO for mobile reception). Bearing in mind simplicity and compatibility with existing broadcast equipment, this option was discarded.

Additionally, when considering the possible balance between 3D services to fixed and to portable receivers it was assumed that fixed users would be the most significant part of the audience and portable receivers would be a secondary target, at least at the first deployment stage. This implies that the multiplexes including a mixture of fixed and portable content would dedicate limited capacity for portable programs.

Finally, In the case of fixed reception, the target coverage areas in the first phase will be urban environments. In countries that have completed the analog to digital transition, the current digital television service area is close to 100% of the population in major cities. This study will maintain this objective, which in other words, implies similar terrestrial network architecture (at least in terms of the number of transmitting sites and radiating patterns). If similar coverage percentages are sought using similar network architecture, in most cases re-using the same sites, the system threshold requirements should not vary too much from current DTV thresholds. In countries that have adopted DVB-T different mode configurations are used nowadays. In all of them the minimum C/N requirement is close to 17 dB. This value will be used as the planning reference. Additionally, in order to study the capacity and throughput balance of the system, a 3 dB margin has been left when selecting the appropriate DVB-T2 mode. Consequently, candidate modes are the ones with C/N requirements in the range from 17 to 23 dB.

B. Backwards Compatibility Scenario: HD and 3D

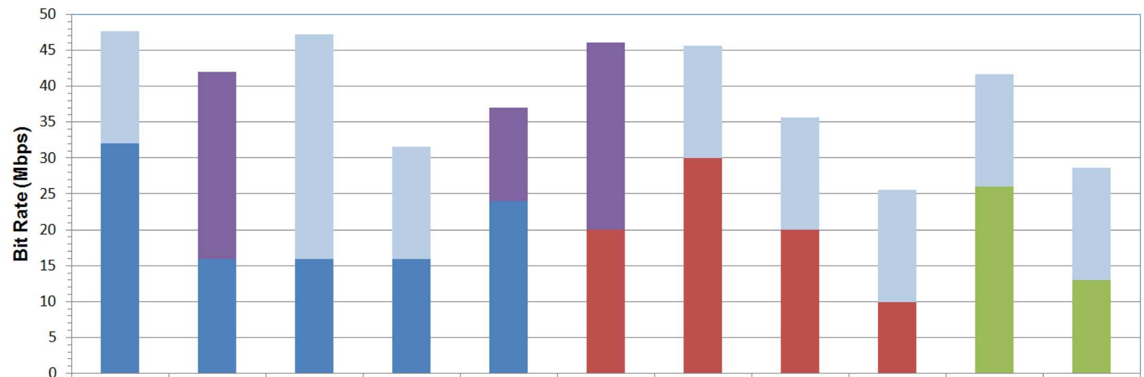
The first scenario is based on a single UHF RF channel that bears a mixture of HD 2D and 3D content with different weights depending on the penetration of 3D services. The situation where this scenario would happen is a first stage of the introduction of 3D contents, where still a majority of the set top boxes are not 3D capable. Using the same RF resources to deliver HD and 3D would allow a smooth introduction from the broadcaster's point of view.

This approach provides flexibility when designing the multiplex contents.

A first alternative would be to keep a static number of programs within the signal in multiple PLPs, in some cases simulcasting HD and 3D services (not always possible due to the significant differences in production of 2D and 3D content) [36]. The second option is to have a dynamic number of programs, with variable number of HD and 3D services depending on the contents (films, sport, news) and time of the day. In both cases, if compatibility with existing HD audience is sought, a minimum set of HD material should always remain in the multiplex.

We have not made a restriction in terms of which of the formats that could be most adequate in this scenario, nor for HD neither for 3D. In the case of HD, advances in the field of video coding [45] suggest that the format to prevail in the future is 1080p. In the case of 3D not all three formats described in previous sections are considered. Bearing in mind that this first scenario is adequate for the initial stages of a 3D service introduction scenario only "3D in 2D" and "2D + Delta" formats have been selected. This scenario does not distinguish service robustness or coverage for HD and 3D. Using the same PLP to deliver HD and 3D services, or provide completely separated PLPs for each type of content would not make any significant difference from the a planning perspective, exception made, perhaps, for signaling management and associated behavior of existing DVB-T2 receivers prior to 3D deployments.

The configuration of the DVB-T2 signal is based on selecting a group of modes as shown in Table III. The first choice to be



	256-QAM-4/5 256-QAM-5/6	256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	256-QAM-4/5 256-QAM-5/6	64-QAM-5/6 256-QAM-3/5 256-QAM-2/3 256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	64-QAM-5/6 256-QAM-2/3 256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	256-QAM-4/5 256-QAM-5/6	256-QAM-4/5 256-QAM-5/6	64-QAM-5/6 256-QAM-3/5 256-QAM-2/3 256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	64-QAM-5/6 256-QAM-3/5 256-QAM-2/3 256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	256-QAM-3/4 256-QAM-4/5 256-QAM-5/6	64-QAM-5/6 256-QAM-3/5 256-QAM-2/3 256-QAM-3/4 256-QAM-4/5 256-QAM-5/6
2D+Delta	15,6	0	31,2	15,6	0	0	15,6	15,6	15,6	15,6	15,6
3Din2D	0	26	0	0	13	26	0	0	0	0	0
1080p	0	0	0	0	0	0	0	0	0	26	13
1080i	0	0	0	0	0	20	30	20	10	0	0
720p	32	16	16	16	24	0	0	0	0	0	0

Fig. 6. Bitrate allocations and mode choices for different combinations of 3D and HDTV formats

TABLE IV
NUMBER OF PROGRAMS, RECOMMENDED MODES, AND PLANNING VALUES IN A 2D HD COMPATIBLE DEPLOYMENT SCENARIO

	Cases: Combination of Services										
HD720p	4	2	2	2	3						
HD1080i						2	3	2	1		
HD1080p										2	1
3Din2D		2			1	2					
2D+Delta	1		2	1			1	1	1	1	1
Total BR(Mbps)	47.6	42	47.2	31.6	37	46	45.6	35.6	25.6	41.6	28.6
DVB-T2 Mode (1)	256 4/5	256 3/4	256 4/5	64 5/6	64 5/6	256 4/5	256 4/5	64 5/6	64 5/6	256 3/4	64 5/6
$E_{\min}^{95\% locations}$ (dBμV/m)	58.6	57.3	58.6	54.3	54.3	58.6	58.6	54.3	54.3	57.3	54.3

(1) Some of the bitrates requirements would allow for more robust modes (i.e., 64QAM-2/3 and even 64 QAM 3/5)

made is related to the network architecture: SFN (Single Frequency Network) or MFN (Multiple Frequency Network). The main difference relies in the guard interval restriction. This approach is based on having the maximum available bitrate, and thus the starting point will be the 32K-Tg 1/128 family of modes (also called *MFN UK Compatible modes*). If a SFN was targeted (32K-Tg 1/16), there is an approximate reduction close to a 10% in the available throughput (depending on the specific mode).

The modes in Table III have been chosen with reception thresholds from 16 to 22.3 dB to target similar network architecture as the one available today (C/N values around 17 dB) as well as optimized architectures that could allow higher values.

Associated to each mode, a useful bitrate is then available to allocate the set of HD and 3D contents. Results of the possible configurations are summarized in Fig. 6.

The configuration choices in Fig. 6 can be studied in three groups. The first five columns show different combinations of 2D, 720p, and 3D services (see Table IV). The results include different allocations of capacity for "3D in 2D" and "2D + Delta". The bitrates required to allocate these choices range from 31.6 to 47.6 Mbps. The best scenario would provide 4 HD programs plus one 2D + Delta service. In the case of 1080i and 1080p the number of services would decrease, and in the best case the capacity would be limited to 3 HD services plus one 3D program.

Minimum field strength values are provided in Table VI for a first planning reference in UHF Band VI. The values are obtained based on the calculation method proposed in [39] and using the minimum required C/N values in Table III. It has been assumed that the target coverage will include a 95% of the locations.

C. Full 3D Scenario: Dedicated DVB-T2 Channel

The planning unit for this second scenario is also an RF channel (one DVB-T2) signal. In this case the HD compatibility restrictions will be avoided, and all the transport capacity

TABLE V
DVB-T2 MODES IN FULL 3D (SFN MODE 32K 1/16)

PLP 1 (Fixed Services)			
Modulation	LDPC Code Rate	BITRATE	Required C/N
64-QAM	4/5	26.98	16.4
64-QAM	5/6	28.12	17.2
256-QAM	3/5	26.98	16
256-QAM	2/3	30.03	17.8
256-QAM	3/4	33.78	20.2
256-QAM	4/5	36.04	21.5
256-QAM	5/6	37.57	22.3
PLP 2 (Mobile Portable)			
Modulation	LDPC Code Rate	BITRATE	Required C/N
QPSK	4/5	2.04	6.8
QPSK	5/6	2.13	7.2
16-QAM	1/2	2.54	7.3
16-QAM	3/5	3.05	9.1
16-QAM	2/3	3.40	10.5

of the RF signal will be dedicated to 3D contents. This approach assumes that there would be enough available broadcasting spectrum for dedicated resources to 3D programming. In this case, a certain amount of the system capacity will be left for 3D portable services. The content for portable users will be multiplexed in a different PLP with increased robustness in the modulation and coding schemes.

This scenario could be theoretically implemented based on any of the three formats to deliver 3D. Nevertheless, if compatibility is not sought with 2D receivers, the "2D + Delta" format is less probable. The "3D in 2D" would be suitable for either portable or fixed services, each case with different modulation and coding parameters. Finally, the "3D in 2D + Enhancement" could be considered a further step that would provide the full resolution of 3D content. In this case, the target would only be fixed receivers. Reduced sizes and resolution in portable devices would probably make "3D in 2D" a format more adequate for this application (see Table V).

The selection of modes has followed parallel paths for portable and fixed parameter selection. In this case, a single frequency network oriented planning is considered to show a different planning exercise. As in the previous subsection, if a MFN mode is sought, there would be an increase of the available bitrate.

The specifications applied to fixed reception are identical to the compatibility scenario. The reference threshold has been 17 dB and modes around this value have been proposed up to 22.3 dB. In the case of portable services, the threshold was set in the range of 7 to 10 dB [47]–[49]. When calculating bitrates and estimating the number of services delivered for fixed and portable reception, the priority has been always given to fixed reception leaving a bitrate of 2–3 Mbps for portable services. Fig. 7 shows the proposed service combinations and suitable modes. The bitrate requirements range in this case from 16 to 34 Mbps, allocated in two separate PLPs, each one with a choice

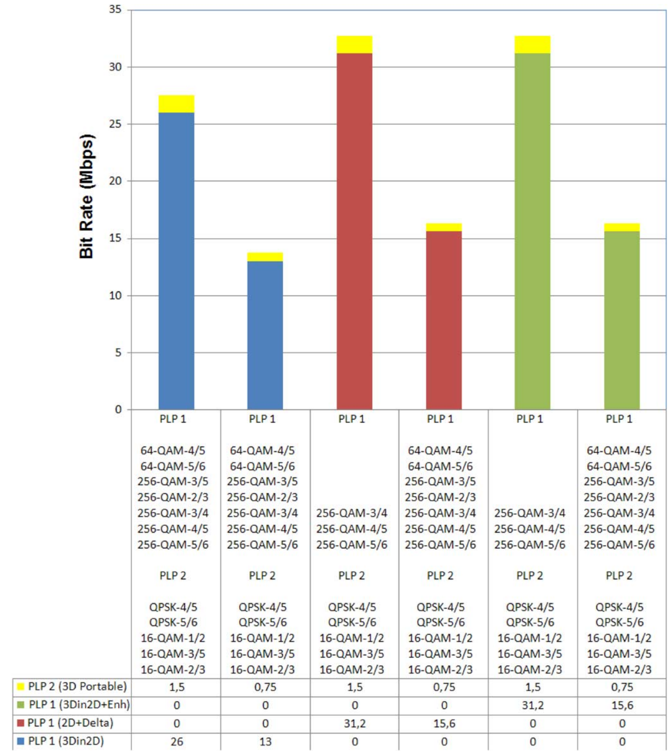


Fig. 7. Fixed and Portable service bitrate combinations in two PLPs. Candidate modes are shown below each bar.

of possibilities. Most combinations for the fixed service PLP are with 256 QAM. The mobile service could be provided either with QPSK or 16 QAM, depending on the C/N restrictions (from 7 dB to 10 dB approximately).

Table VI summarizes the number of 3D services that could be delivered in the full 3D scenario. The best scenario would include two full resolution 3D programs and one portable service. The recommended mode for portable reception would be QPSK 4/5. This mode would cover any of the use cases shown and probably will also have good performance in mobile scenarios.

Field strength values are also shown in Table VI. The planning value for fixed is in the same range [50–60 $\mathrm{dB}\mu\mathrm{V/m}$] as for the previous scenario (mixed HD and 3D), while the portable mode would require a considerably higher value if a high percentage of the locations is sought. This requirement will probably lead to a densification of the broadcast networks if portable (and even more for mobile) consumers are targeted with coverage objectives close to 100% [37].

VII. CONCLUSION

This paper has presented an analysis of the possibilities offered by the DVB-T2 standard to roll out 3D services in two different scenarios.

Due to the lack of a standard, the work has been based on considering several 3D image formats considered by the industry as the potential candidates to be used in the mid term for 3DTV. The choice of formats is "3D in 2D", "2D + Delta" and "3D in 2D + Enhancement" layer. Each one presents advantages and problems, associated to definition (image quality), compatibility

TABLE VI
NUMBER OF PROGRAMS, RECOMMENDED MODES, AND PLANNING VALUES IN A FULL 3D SCENARIO (FIXED AND PORTABLE SERVICES)

	Cases: Combination of Services					
3D in 2D	2	1				
2D + Delta			2	1		
3D in 2D + Enh.					2	1
3D Portable	2	1	2	1	2	1
Total Bitrate (PLP1)	26	13	31.2	15.6	31.2	15.6
Total Bitrate (PLP2)	1.5	0.75	1.5	0.75	1.5	0.75
DVB-T2 Mode (PLP1)	64 4/5	64 4/5	256 3/4	64 4/5	256 3/4	64 4/5
DVB-T2 Mode (PLP1)	QPSK 4/5					
$E_{min}^{95\% locations}$ (dBμV/m) (PLP1)	53.5	53.5	57.3	53.5	57.3	53.5
$E_{min}^{99\% locations}$ (dBμV/m) (PLP2)	80.9					

with existing 2D receivers not forgetting the complexity associated to video coding. At the time of writing this paper the first display systems are already on sale, mostly based on the "3D in 2D" approach. As mentioned, the absence of a standard does not ensure that this one will be the format in the future.

One of the scenarios described includes HDTV and 3D services in the same DVB-T2 spectrum. In order to make the study applicable in a variety of situations, a set of possible HDTV configurations (formats and bitrates) has also been described.

Once the content formats and bitrates have been established, the work has proposed two scenarios. The first one proposes a simultaneous delivery of 3D and HDTV services for fixed receivers in the same multiplex, exploiting the PLP flexibility of the DVB-T2 standard. A possible choice of DVB-T2 modes has been proposed and some of the initial planning parameters have been described. In this case, the number of HDTV programs ranges from 1 to 4 and the number of 3D programs is 1 or 2 using 32K and 256QAM modes. Modes proposed require a minimum C/N ratio close to 17 dB, excepting for two cases with capacities close to 50 Mbps (22.3 dB). Most of the choices shown would allow maintaining similar network architecture to the one in traditional DTV services.

The second approach avoids some of the constraints associated to compatibility with 2D receivers. In this case, the full capacity of a DVB-T2 signal is used to deliver 3D programs and the image formats considered are "3D in 2D", that could be considered as standard definition 3D and "3D in 2D + Enhancements" that could be regarded as high definition 3D. The scenario has also included 3D portable services in the same DVB-T2 signal, with a dedicated PLP with increased robustness for this purpose. The number of programs in this second alternative is one or two for fixed reception, depending on the image format selected, and another one or two for portable receivers.

The results prove that the DVB-T2 standard has enough flexibility to convey both HD and 3D services in a variety of system configurations appropriate for different roll out cases. It should be noted that there is still a considerable amount of work, both technical and business development related to be done until a commercial networks are set up.

REFERENCES

[1] *Digital Video Broadcasting (DVB): Frame Structure, Channel Coding and Modulation for a Second Generation Digital Terrestrial Television Broadcasting System (DVB-T2)*, EN 302 755 V.1.1.1., European Telecommunications Standard Institute ETSI, Sep. 2009.

[2] O. Bendov, Y. Wu, C. W. Rhodes, and J. F. X. Browne, "Planning factors for fixed and portable DTTV reception," *IEEE Trans. Broadcast.*, vol. 50, no. 3, pp. 209–223, Sep. 2004.

[3] A. Arrinda, M. M. Velez, P. Angueira, D. de la Vega, and J. L. Ordiales, "Digital terrestrial television (COFDM 8K system) field trials and coverage measurements in Spain," *IEEE Trans. Broadcast.*, vol. 45, no. 2, pp. 171–176, Jun. 1999.

[4] G. Faria, J. A. Henriksson, E. Stare, and P. Talmola, "DVB-H: Digital broadcast services to handheld devices," *Proc. IEEE*, vol. 94, no. 1, pp. 194–209, Jan. 2006.

[5] DVB Consortium, "DVB commercial requirements for DVB 3D-TV," Jul. 2010 [Online]. Available: www.dvb.org

[6] E. Stoykova, A. Alatan, P. Benzie, N. Grammalidis, S. Malassiotis, J. Ostermann, S. Piekh, V. Sainov, C. Theobalt, T. Thevar, and X. Zabulis, "3-D time-varying scene capture technologies—A survey," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 17, no. 11, Nov. 2007.

[7] O. Grau and V. Vinayagamoorthy, "Stereoscopic 3D sports content without stereo rigs," Research White Paper, WHP180, BBC, Nov. 2009.

[8] N. Hur, G. Lee, W. You, J. Lee, and C. Ahn, "An HDTV-Compatible 3DTV Broadcasting System," *ETRI J.*, vol. 26, no. 2, Apr. 2004.

[9] A. Kolb, E. Barth, and R. Koch, "ToF-Sensors: New Dimensions for Realism and Interactivity," in *IEEE Conf. Comput. Vis. Pattern Recog. Workshops*, 2008.

[10] A. Redert *et al.*, "Advanced three-dimensional television system technologies," in *Proc. 1st Int. Symp. 3D Data Process. Vis. Transmiss.*, 2002, pp. 313–319.

[11] A. Frick, F. Kellner, B. Bartczak, and R. Koch, "Generation of 3D-TV LDV-content with the time of flight camera," in *3DTV Conf. (3DTV-CON)*, May 2009, pp. 1–4.

[12] A. Frick, B. Bartczak, and R. Koch, "3D-TV LDV content generation with a hybrid ToF-multicamera RIG," in *3DTV Conf. (3DTV-CON)*, Jun. 2010, pp. 1–4.

[13] "i3DLive: Interactive 3D methods for live-action media project," 2009–;2011 [Online]. Available: http://www.bbc.co.uk/rd/projects/2009/10/i3dlive.shtml

[14] L. Yan, Z. Zhaoyang, and A. Ping, "Stereo video coding based on frame estimation and interpolation," *IEEE Trans. Broadcast.*, vol. 49, no. 1, Mar. 2003.

[15] A. Smolic, K. Mueller, N. Stefanoski, J. Ostermann, A. Gotchev, G. B. Akar, G. Triantafyllidis, and A. Koz, "Coding Algorithms for 3DTV—A survey," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 17, no. 11, Nov. 2007.

[16] S. Sun and S. Lei, "Stereo-view video coding using H.264 tools," in *Proc. SPIE Image Video Commun. Process. 2005*, Mar. 2005, vol. 5685, pp. 177–184.

[17] "Coding of audio-visual objects-Part 2: Visual," ISO/IEC 14496-2 (MPEG-4 visual version 1), Apr. 1999; ISO/IEC JTC 1, Amd. 1 (ver. 2), Feb. 2000; Amd. 2, 2001; Amd. 3, 2001; Amd. 4 (streaming video profile), 2001.

[18] L. Zhang and W. J. Tam, "Stereoscopic image generation based on depth images for 3DTV," *IEEE Trans. Broadcast.*, vol. 51, no. 2, pp. 191–199, 2005.

[19] C. Fehn, "3D-TV using depth-image-based rendering (DIBR)," in *Proc. Picture Coding Symp.*, San Francisco, CA, Dec. 2004.

[20] C. Fehn, P. Kauff, M. Op de Beeck, F. Ernst, W. IJsselsteijn, M. Pollefeys, L. Van Gool, E. Ofeck, and I. Sexton, "An evolutionary and optimized approach on 3D-TV," in *Proc. Int. Broadcast Conf.*, Amsterdam, The Netherlands, Sep. 2002, pp. 357–365.

[21] P. Merkle, A. Smolic, K. Muller, and T. Wiegand, "Efficient prediction structures for multiview video coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 17, no. 11, pp. 1461–1473, Nov. 2007.

[22] P. Merkle, A. Smolic, K. Muller, and T. Wiegand, "Coding efficiency versus complexity of MVC prediction structures," in *Proc. EUSIPCO*, Poznan, Poland, Sep. 3, 2007.
[23] P. Merkle, A. Smolic, K. Muller, and T. Wiegand, "Multi-view video plus depth representations and coding technologies," in *IEEE Conf. Image Process.*, pp. 201–204.
[24] L. S. Karlsson and M. Sjostrom, "Multiview plus depth scalable coding in the depth domain," in *3DTV Conf.*, pp. 1–4.
[25] "DTT networks in evolutions-Making changes to the digital terrestrial television platform," DigiTAG Report, May 2008 [Online]. Available: http://www.digitag.org/
[26] "Transforming the digital dividend opportunity into social benefits and economic growth in Europe," Jul. 2009, European Union. EC Consultation document.
[27] "European Broadcasting Union (EBU). EBU response to the EC consultation document, Transforming the digital dividend opportunity into social benefits and economic growth in Europe," Sep. 2009.
[28] N. Hur, G. Lee, W. You, J. Lee, and C. Ahn, "An HDTV-Compatible 3DTV Broadcasting System," *ETRI J.*, vol. 26, no. 2, Apr. 2004.
[29] H. Lee, K. Yun, N. Hur, J. Kim, B. C. Min, and J. K. Kim, "A structure for 2D/3D mixed service based on terrestrial DMB system," in *Proc. 3DTV Conf.*, Kos Island, Greece, 2007.
[30] P. Benzie, J. Watson, P. Surman, I. Rakkolainen, K. Hopf, H. Urey, V. Sainov, and C. von Kopylow, "A survey of 3DTV displays: Techniques and technologies," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 17, no. 11, Nov. 2007.
[31] L. Onural, T. Sikora, J. Ostermann, A. Smolic, M. R. Civanlar, and J. Watson, "An assessment of 3DTV technologies," in *NAB BEC Proc.*, 2006, pp. 456–467.
[32] P. Surman, K. Hopf, I. Sexton, W. Kai Lee, and R. Bates, "Development of Viable Domestic 3DTV Displays," in *3–D Television, Capture, Transmiss., Disp.*, H. M. Ozaktas and L. Onural, Eds. New York: Springer, 2008, ch. 13.
[33] L. Onural and H. M. Ozaktas, "Three-dimensional television: From science-fiction to reality," in *3–D Television, Capture, Transmiss., Disp.*, H. M. Ozaktas and L. Onural, Eds. New York: Springer, 2008, ch. 1.
[34] International Telecommunications Union, features of 3DTV video systems for broadcasting," Geneve, Report ITU-R. BT.2160, Apr. 2009, ITU-R.
[35] Dolby Laboratories, Inc., "Dolby open specification for frame-compatible 3D systems," S10/22833, 2010, Issue 1.
[36] "Telefoniaktiebolajet LM Ericsson. EricssonWhite Paper:. 3D television. Taking television to a new dimension," 2010 [Online]. Available: www.ericsson.com
[37] J. Arenas, P. Angueira, M. Vélez, D. de la Vega, A. Arrinda, and J. L. Ordiales, "Network planning for delivering digital television to mobile and portable devices: A hybrid broadcast and cellular approach," in *48th IEEE Broadcast Technol. Soc. Ann. Symp.*, Washington, D.C., Oct. 2008.
[38] DVB CM-NGH, Commercial Requirements for DVB-NGH V.1.01 [Online]. Available: http://www.dvb.org/technology/dvb-ngh/
[39] "Digital video broadcasting (DVB); DVB-H implementation guidelines," DVB Document A09r3, Apr. 2009.
[40] H. Hoffmann, T. Itagaki, D. Wood, and A. Bock, "Studies on the bit rate requirements for a HDTV format with 1920 1080 pixel resolution, progressive scanning at 50 Hz frame rate targeting large flat panel displays," *IEEE Trans. Broadcast.*, vol. 52, no. 4, Dec. 2006.
[41] H. Hoffmann, T. Itagaki, D. Wood, T. Hinz, and T. Wiegand, "A novel method for subjective picture quality assessment and further studies of HDTV formats," *IEEE Trans. Broadcast.*, vol. 54, no. 1, Mar. 2008.
[42] J. Klein, M. Reynolds, and D. Johnston, "Advice on spectrum usage, HDTV and MPEG-4," Aug. 2007 [Online]. Available: http://www.bbc.co.uk/bbctrust/index.shtml
[43] R. Brugger and A. Gbenga-llori, "Spectrum usage and requirements-for future terrestrial broadcast applications," EBU Technical Review, Q4 17/17, 2009.
[44] N. Hur, "3D DMB: A portable, Mobile 3D-TV," in *3D Television Workshop*, Shanghai, Mar. 2010 [Online]. Available: http://www.ieee.org/organizations/society/bt/
[45] M. Sugawara, K. Mitani, M. Kanazawa, F. Okano, and Y. Nishida, "Future prospects of HDTV-Technical trends toward 1080p," in *IBC Conf. Pub.*, Amsterdam, Sep. 2005.
[46] A. Tikanmäki, A. Gotchev, A. Smolic, and K. Müller, "Quality assessment of 3D video in rate allocation experiments," in *Proc. IEEE Int. Symp. Consum. Electron. (ISCE)*, Algarve, Portugal, Apr. 2008.
[47] S. Cho, G. Lee, B. Bae, K. Yang, C. Ahn, S. Lee, and C. Ahn, "System and Services of Terrestrial Digital Multimedia Broadcasting (T-DMB)," *IEEE Trans. Broadcast.*, vol. 53, no. 1, pp. 171–178, Mar. 2007.
[48] Y. Lee, S. Lee, Y. Kim, S. Lee, Z. Yim, B. Choi, S. Kim, and J. Seo, "Field trials for terrestrial digital multimedia broadcasting system," *IEEE Trans. Broadcast.*, vol. 53, no. 1, pp. 425–433, Mar. 2007.
[49] M. Poggioni, L. Rugini, and P. Banelli, "DVB-T/H and T-DMB: Physical layer performance comparison in fast mobile channels," *IEEE Trans. Broadcast.*, vol. 55, no. 4, pp. 719–730, Dec. 2009.

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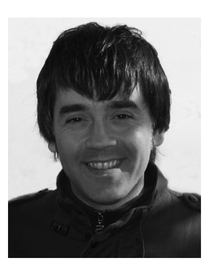

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