State of the art of technology and standards

Atanas Gotchev ■ Karsten Müller ■ Gozde Bozdagi Akar
Dominik Strohmeier ■ Ivan Pushkarov

MOBILE3DTV

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Keywords: mobile 3DTV, MPEG, DVB-H, DVB-SH, SMPTE, ITU-T, VQEG, multimedia platforms, auto-stereoscopic displays, user experience, quality of experience, objective video quality metrics

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Author(s): Atanas Gotchev (TTY), Karsten Müller (FHG), Gozde Bozdagi Akar (METU), Dominik Strohmeier (TUIL), Ivan Pushkarov (MMS)
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Executive Summary

In this report, we overview the RTD activities in the area of mobile 3D video and related fields over the period of May 2008 – June 2009. The review is structured in three parts: standards, systems and research. Standards determine the industry and community acceptance of novel technology developments. Systems show how standards have been successfully employed. Research opens new horizons by going beyond standards and currently available systems.

Section 2 is devoted to recent standardization activities in the area. We overview the activities of MPEG toward new multi-view and 3D video coding standards. Then, we address the video transmission-related standards. Here, the recent developments by the DVB project, i.e. DVB-H and DVB-SH are reviewed first followed by the SMPTE activities toward 3D delivery to the home. In the area of user studies, we review the standardization activities of ITU-T focused on quality of experience and respective assessment methodologies and of VQEG focused on objective video quality assessment.

Section 3 is devoted to devices and systems. We overview the development of new embedded platforms and auto-stereoscopic displays for their applicability to handheld devices and we describe known experimental 3DTV and mobile 3DTV systems.

Section 4 reviews recent research activities in terms of projects and results reported in journal and conference papers. We describe relevant projects, mainly within EU's FP7, but also in Asia. We also briefly review research works which support, extend or go beyond standardization activities. The same topics of interest as in our project are addressed, namely coding, error resilience, user studies and video quality enhancement.

In the conclusions, we try to identify the major trends in the overviewed technology and standards.

Numerous sources of information, including standards, recommendations, HW and SW references, journal articles, conference papers, research and corporate web sites, and press releases have been used in the review. The reference list includes 122 sources of information.

Table of contents

1 Introduction

The mobile 3DTV value chain has modules related with content creation and coding, error-resilient transmission over wireless channel, and receiving and playing on handheld devices equipped with appropriate auto-stereoscopic displays. All these technology components are naturally spanned by the user experience of the respective multimedia content. In order to successfully develop new solutions and gather new knowledge about the respective technology and its acceptance, within the MOBILE3DTV project we have been following and comparing our efforts with the state-of-the-art in the field.

This report represents a yearly snapshot of the mobile 3DTV technology field. Its mosaic is formed by three main segments: standards, systems, and research. We start with standardization activities as they are a quite informative indicator about what is going to be accepted by the industrial players in the field. We review the recent standardization attempts related with the coding, transmission, user studies, and quality assessment of mobile 3DTV content. Further, we review the emerging new media-reach platforms and auto-stereoscopic displays being the core of a productive and low-power-consuming device with appropriate form factor and high-quality 3D display capabilities. Finally, we concentrate on forefront research described through projects and academic publications. These are considering a source of novel ideas and advance solutions for further standardization and practical use. In the conclusions, we identify trends within the reviewed field.

2 Standards

2.1 Coding-related standards

Standardization of digital audio and video is investigated by the Moving Picture Experts Group (MPEG), a working group of ISO/IES and the corresponding standards are issued with ISO/IES designations [1]. The starting point of 3D video coding was the family of coding standards for classical 2D video with Advanced Video Coding (AVC/H.264), jointly developed by ISO/IEC MPEG and ITU/VCEG within the Joined Video Team (JVT). Based on that, new extensions of video coding standards for 3D video content were or are being developed, as described below.

2.1.1 Multi-view Video Coding

3D video (3DV) and free viewpoint video (FVV) are new types of visual media that expand the user's experience beyond what is offered by 2D video. 3DV offers a 3D depth impression of the observed scenery, while FVV allows for an interactive selection of viewpoint and direction within a certain operating range. A common element of 3DV and FVV systems is the use of multiple views of the same scene that are transmitted to the user.

Multiview Video Coding (MVC, ISO/IEC 14496-10:2008 Amendment 1) is an extension of the Advanced Video Coding (AVC) standard that provides efficient coding of such multiview video. The overall structure of MVC defines the following interfaces: The encoder receives *N* temporally synchronized video streams and generates one bitstream. The decoder receives the bitstream, decodes and outputs the *N* video signals.

MVC was standardized in July 2008 in a first version [2]. Current work in MPEG investigates MVC suitability for interlaced multiview video content.

For the case of stereo-video, that is two separate views coded together, a promising extension is to study view subsampling, i.e. one full resolution view + one subsampled view. The idea behind this approach is that the human visual system is capable to retrieve the stereo with the quality of the better channel. This approach however is only suitable for two views. For more views, this idea was rejected by MPEG, since in N>2 view scenarios it is not clear, which views and how many shall be subsampled.

One drawback of MVC is that the compressed bitstream still requires a datarate, which is linearly dependent on the number of views.

2.1.2 3D Video Coding

3D Video Coding (3DVC) is a standard that targets serving a variety of 3D displays, including stereoscopic displays with different sizes and baselines and multi-view displays [10]. The latter present N views (e.g. N = 9) simultaneously to the user, so-called multi-vied displays. For efficiency reasons only a lower number K of views (K = 1,..,3) shall be transmitted. For those K views additional depth data shall be provided. At the receiver side the N views to be displayed are generated from the K transmitted views with depth by depth image based rendering (DIBR).

This application scenario imposes specific constraints such as narrow angle acquisition (< 20 degrees). Also there should be no need (cost reasons) for geometric rectification at the receiver side, meaning if any rectification is needed at all it should be performed on the input views already at the encoder side.

The representation format is based on K out of N views, augmented with depth sequences. This representation related to stereo-video generalizes the possibilities of MPEG-C, Part 3 and MVC, i.e. the two separate views can be coded together or can be reduced to single view + depth with the second view to be synthesized at the receiver.

3DVC is an ongoing MPEG activity, where currently test material is collected with good depth data and first reference coding is provided. Here, the standardized MVC is used to code 2 views by jointly coding the color data in one MVC stream as well as the depth data in a second MVC stream. After enough high-quality test data with depth maps is available and reference MVC coding of all data has been carried out, a call for proposals for new 3D video coding technology will be issued. For 3DVC, a standard is expected in 2010/2011. [4]-[13].

2.2 Transmission-related standards

2.2.1 DVB for Mobile TV

By year 2009 DVB Project Office defined a group of technologies to enable mobile TV services, namely DVB-H, DVB-SH and DVB-IPDC.

Delivery of digital terrestrial TV services to handheld devices was first discussed under the well-proven ETSI standard DVB-T. Soon after it was discovered that some new features were required considering the power saving and robust transmission for cellular environment. Aiming the efficient delivery of IP-encapsulated data over terrestrial networks, DVB-H is published as a formal standard (EN 203 204) by ETSI in November 2004, mainly based on DVB-T physical layer with two new features added at link layer to overcome these challenges. In order to achieve an efficient power consumption at the battery powered receivers,a new technique called time-slicing is implemented where receiver gets bursts of data periodically and power offs in between. Challenges due to mobility of the user are overcome by the introduction of an additional forward error correction at the link layer. The latest published report for DVB-H implementation includes recommendations regarding the latest research on channel models, influences on signal reception for network planning and services [77].

As it is in the definition, since DVB-H considers the content delivery in the IP format, the next step after the creation of DVB-H was improving the IP datacasting standars of DVB mainly referred as DVB-IPDC [74], [80]. These specifications for IP Datacast are essential to the convergence of broadcast networks and cellular networks. The specifications cover the overall system architecture, electronic service guide (ESG), content delivery protocols (CDP), and the PSI/SI. Latest IPDC BlueBook regarding Content Delivery Protocols (CDP) provides detailed information for implementation file delivery, media streaming and error protection at application layer [75]. Similarly, a new version regarding ESG defines the syntax definitions for ESG data model as zapping support [78], [79] and a new version regarding PSI/SI has been published in early 2009 [76]. Also, a new version of specification for the audio/video coding and transmission via MPEG-2 TS format has been published [84].

DVB-SH is the name of a transmission system standard designed to deliver video, audio and data services to vehicles and handheld devices. The key feature of DVB-SH is that it’s a hybrid satellite/terrestrial system that allows the use of a satellite to achieve coverage of large regions or even a whole country. The DVB-SH system was designed for frequencies below 3 GHz, supporting UHF band, L Band or S-band. It complements and improves the existing DVB-H physical layer standard. It is based on DVB IP Datacast (IPDC) delivery, electronic service guides and service purchase and protection standards.

DVB-SH specifies two operational modes:

- SH-A uses OFDM both on the satellite and the terrestrial link.
- SH-B uses Time-Division Multiplexing (TDM) on the satellite link and COFDM on the terrestrial link.

The DVB-SH incorporates a number of enhancements when compared to DVB-H:

- More alternative coding rates are available
- The omission of the 64QAM modulation scheme
- The inclusion of support for 1.7 MHz bandwidth and 1k FFT
- FEC using Turbo coding
- Improved time interleaving
- Support for antenna diversity in terminals

EU has officially endorsed DVB-H as the mobile TV technology of choice in Europe in March 2008. The aim was to establish a single market for Mobile TV by promoting DVB-H to its competitor MediaFLO (similar mobile TV technology by Qualcomm) that will enable all EU citizens to watch TV on the move. It was foreseen that Mobile TV could reach a market of up to € 20 billion by 2011, reaching some 500 million customers worldwide [123] . During 2008 and 2009, DVB-H services have been launched in a number of cities.

Number of broadcast mobile TV technologies launched till 2009 are given in Table 1. However by the first quarter of 2010, expansion of the technology seems to be slow in Europe which makes the future of DVB-H a hot discussion topic. The unsatisfying growth of DVB-H is directly related to the success of MBMS services via 3G networks. The lack of available devices, the necessity of re-equipment for transmission and reception and service being already available on 3G networks seem to be the main reasons why the mobile operators refuse to invest in a new network. Another issue is that although DVB-SH is developed to improve the performance of mobile reception in urban areas, same reasons apply for that network too. In addition to this, current developments in terrestrial video broadcast make DVB-H a comparably old technology and requires a newer mobile standard. Therefore the development of a new standard has started and the publications of Next Generation Handheld standards are expected in 2011 and first commercial devices to be ready in 2013. In conclusion, there seems to be certain reasons for the decline in the deployment of DVB-H recently.

Looking at specific countries, in Austria, DVB-H became available by UEFA Euro 2008. However, Mobilkom Austria plans to stop offering mobile TV services via DVB-H by the end 2010 due to a lack of mobile phones with DVB-H, according to Austrian press agency APA. In Morocco, the service has been launched in May 2008. In Switzerland DVB-H again became available since the start of UEFA Euro 2008. However, by March 2010, Swisscom TV offered a new mobile TV product, replacing its previous DVB-H service. The new mobile TV offer will use HSPA/UMTS/Edge instead. The DVB-H network will remain in place for the time being. In Germany, the future of DVB-H is still unknown due to continuing issues with the license and open questions about the business model, in particular which role operators play in it and if they are willing to do so. In Iran, DVB-H services began in Tehran in March 2008. The service brings ten television and four radio channels to mobile phones. In May 2008, In May, 2008, Conseil Superieur de l'Audiovisuel (CSA) has granted authorizations for 16 pre-listed TV broadcasters to provide mobile TV services based on the DVB-H standard in France. However, since that time, the national Mobile Network Operators are not keen to invest in network construction; instead they prefer betting on the evolution of mobile broadband technologies such as 4G-LTE.

Regarding 3D technologies, the technical module of DVB project has formed a special group and conducted a meeting to explore the possibilities of 3DTV broadcasting (TM-3DTV). In March 31th, 2010 a press release is published on DVB website anouncing the possible start of 3DTV broadcasting in year 2010. The press release also anounces that certain football matches will be shot in 3DTV.

Country	Launched	MoTV Handsets End of 2007	MoTV Handsets End of 2008	MoTV Handsets End of 2009	Technology
Brazil	2008	0	0	150,000	ISDB-T
China	2008	0	600,000	5,000,000	CMMB/STiMi
Germany	2008	0	10,000	50,000	DVB-T
Italy	2006	700,000	850,000	1,000,000	DVB-H
Japan	2006	25,000,000	40,000,000	60,000,000	ISDB-T
Netherlands	2008	0	90,000	180,000	DVB-H
Russia	2006	10,000	20,000	30,000	DVB-H
South Korea	2005	1,500,000	1,850,000	2,000,000	S-DMB
South Korea	2006	13,000,000	15,400,000	17,500,000	T-DMB
USA	2007	50,000	100,000	400,000	MediaFLO
Other	Various	50,000	65,000	275,000	Various
		40,310,000	**58,985,000**	**86,585,000**	

Tale 1: Broadcast mobile TV technologies (Source: Rethink Research)

SMPTE Task Force on 3D to the Home

The Society of Motion Picture and Television Engineers (SMPTE) has formed a Task Force on "3D Home Display Formats" in order to find out what standards are required to establish easy distribution of stereoscopic image content via multiple types of distribution channels (e.g. packaged, broadcast, satellite, cable, internet). Therefore the main scope of 3D Task Force is Home Master requirements with consideration from content creation, distribution and display. By defining standards, rapid adoption of this content on a fixed home display is expected. There are four major teams with specific work areas within the task force namely, Issues & Challenges Team, Minimum RequirementsTeam and Evaluation Criteria Team. Since August 2008 monthly face-to-face meetings and weekly teleconferences are being held. Task Force is in interaction with other communities such as ATSC, DVB, ITU-R, MPEG and CEA. Task Force has provided a technical report on their studies and can be accessed from the SMPTE website [85] and a summary of the report can be found in [86].

2.3 User-studies related standards

Current activities within standardization processes focus on defining Quality of Experience and its assessment. Quality of Experience is defined as “the overall acceptability of an application or service, as perceived subjectively by the end-user“[92].

2.3.1 ITU-T G.1080 “Quality of experience requirements for IPTV services”

ITU-T G.1080 was pre-published in December 2008 [91]. It is the first ITU recommendation tackling the challenge of understanding Quality of Experience (QoE). ITU-T G.1080 defines user requirements for QoE related to IPTV services. The requirements provide information about Quality of Experience for video and audio, text and graphics, control functions, and meta-data or Content navigation. All requirements are defined from the perspective of end-users. Additionally, ITU-T G.1080 discusses the interaction between Network Quality of Service parameters that affect QoE, especially transmission impairments.

ITU-T G.1080 also refers to users' expectation and context of use when defining the scope of Quality of Experience. It is also outlined that cultural background, motivation, attention, or the emotional state of the end users have influence of QoE responses. However, ITU-T G.1080 limits their requirements to IPTV systems in SDTV (standard definition television) or HDTV (high definition television). Mobile scenarios (e.g. lower resolutions, smaller screen sizes) are not considered.

2.3.2 ITU-T Draft Rec. G.RQAM "Reference guide to QoE assessment methodologies"

The scope of ITU-T G.RQAM [90] is to provide a reference to current QoE assessment methods of different standardization bodies. ITU-T G.RQAM takes into account subjective and objective, i.e. instrumental, assessment methods and offers classification criteria for both approaches. The target services of G.RQAM for QoE assessment are mainly audio and video telecommunications services such as voice messaging, videoconferencing, or streaming applications.

2.4 Standardization related with quality metrics

2.4.1 Video Quality Experts Group

Video Quality Experts Group (VQEG) has been established with the aim to standardize objective video quality metrics. First attempts have been to test and evaluate the performance of full-reference metrics, measuring the quality of block-based encoders such as MPEG-2 and H.263 with bit-rate between 768 kbps and 36 Mbps. In so-called 'Phase I' round of tests, nine different algorithms for objective quality measurement were compared against subjective tests, carried in accordance with ITU-R recommendation BT.500 [109], [112]. The objective metrics were tested by the proponents and verified by independent laboratories [111]. No single superior objective model for all cases was found, and no model was able to predict subjective quality scores with sufficient accuracy [110]. Between 2001 and 2003 VQEG has performed second round of tests, also known as "Phase II". Based on the results, VQEG has proposed four of the algorithms as having sufficient precision in predicting the subjective quality scores [113].

At its meeting in September 2008, VQEG has decided to form a 3DTV group to investigate how to measure visual quality of 3D television. No activity of this group has been announced yet.

3 Devices and systems

3.1 Multimedia platforms

The mobile multimedia devices market has been targeted by a number of flexible platforms. Leading vendors such as Texas Instruments, Intel, and Qualcomm have developed platforms and chips tailored especially for mobile devices.

TI has continued its OMAP series by introducing OMAP 4. The new platform is armed with perfect balanced power efficiency and high performance system-on-chip. It includes two application processors, based on the dual-core Cortex-A9 MPCore general purpose processor. The OMAP4 application processor has IVA 3 based hardware acceleration, delivering true 1080p HD processing (recording and playback). Image Signal Processor is also embedded to the platform targeting g digital SLR-like performance. The device has Imagination Technologies POWERVR™

SGX540 3D graphics core for stunning 3D user interfaces and high Intensity 3D mobile gaming. OMAP4 supports all interfaces, required in modern mobiles plus a variety of other interfaces required by multimedia devices. These include composite TV output; HDMI v1.3 output to drive HD displays; WUXGA display support; peripheral interfaces such as MIPI serial camera; serial display interfaces, SLIMbusSM, MMC/SD, USB 2.0 On-The-Go; High Speed, UART, SPI, and more. The platform is supported by all leading mobile operating systems including MS Windows Mobile, Symbian and Linux (Android or Limo).

A competing platform is the Qualcomm's Snapdragon™. It offers a combination of processing performance and optimized power consumption. The core is formed by a 1 GHz general-purpose processor and a 600 MHz digital signal processor. The platform supports high-definition (720p) video decoding, and has multiple video codec support. WXGA (1280x780) High-resolution LCD can be attached to the platform. The platform support wide variety of audio codecs, such as: AAC+; eAAC+; FR, EFR, HR, WB-AMR, G.729a, G.711, etc. Connectivity is supported by integrated 3G mobile broadband. The platform also supports Wi-Fi and Bluetooth connectivity, mobile broadcast TV such as: MediaFLO, DVB-H and ISDB-T. Build-in seventh-generation gps One engine with Standalone-GPS and Assisted-GPS modes is presented. The platform supports MS Windows Mobile, Android, and a number of Linux-based OSs.

3.2 Displays and devices

During last months, several commercial and prototype 3D displays for mobiles have been announced.

The Japanese manufacturer Hitachi and the cellular services provider KDDI have announced a feature-rich phone model branded as Hitachi WOO Ketai H001 3D telephone [100]. This product is for the Japanese market only. While having all the modern features presented in modern mobile communicators, the focus of this phone is on the 3D display. The underlying technology is parallax barrier and the display is in switchable 2D/3D mode both in vertical and horizontal direction. The display has 3.1 inch diagonal length, and resolution of 854x480 pixels. Among the installed applications, one allows the user to adjust the depth of the perceived stereo image. Considering the potential stress that the display causes to the eyes, the producer has issued a warning that the device should not be used by children under the age of 6. According to an InsightMedia report [108], the display of that mobile phone comes from the Korean company MasterImage. Based on the announced characteristics and display technology, it seems that the display is very similar to the display by MasterImage, the Mobile3DTV project has been experimenting with for a year [106]. According to the same InsightMedia report, MasterImage supported by the Korean technology company KDC Communications, has been delivering 3D LCD panels to other producers in Taiwan and China. KDC has been adjusting its mass-production line at Telson, Korea to enlarge the delivery of such displays.

Another device is the Samsung SCH-B710 [101]. This is full 3D multimedia device, featuring DMB broadcast, 3D camera (dual-camera capable of shooting two images simultaneously), and 3D LCD. The 3D LCD has a 2.2 inch diagonal and resolution of 240x320 pixels. The 3D effect is created by a parallax barrier. New feature for a mobile device is the PIP function allowing the user to simultaneously observe two things. The lack of stereo video content is compensated by a 2D to 3D application by DDD installed in the phone. Thus, mobile TV is converted to 3D within the phone. The phone was demonstrated by Orange at the Dimension 3 Expo held on 2-4 June 2009 in Paris. We had the chance to test the phone – the stereo camera delivers stereo images and video directly observable on the display. The 3D effect however, is quite limited and the 2D to 3D conversion is somewhat unnatural.

A 3D solution was developed for the iPhone by Spatial View Inc under the brand of Wazabee [102]. This iPhone application consists of protective case with removable front optical filter. The glass is a micro-lens barrier which creates the stereo effect. After placing the 3D filter, the phone is hard to navigate, that means one can use the phone either in 2D or 3D mode. Some tests have reported the 3D effect produced by this technology being causing fatigue for the eyes.

Toshiba Matsushita Display has announced at CES a portable 3D display. The display relies on the Toshiba Matsushita Optically Compensated Bend (OCB) technology to provide faster full-resolution 3D imaging. Two modules, namely 3" and 9" high-resolution panels have been demonstrated at CES. Information sources say that the technology does not employs additional lens and glasses, but creates the 3D effect by appropriately controlling the background lights. The displays are reported to be cheaper than lenticular-based ones and providing the same resolution in 2D and 3D [121]. The same 3'' display has been demonstrated at the SID symposium in San Antonio in June 2009 [122].

Meanwhile, the 3D display produced by NEC LCD by the unique horizontal double density pixel (HDDP) arrangement and adopted by the Mobile3DTV project has been demonstrated at several exhibitions, including the World Mobile Congress in January in Barcelona [119] and the Dimension 3 Expo in June in Paris [120].

3.3 Experimental systems

In a research project, the Electronics and Telecommunication Research Institute (ETRI), South Korea has developed a 3DTV system over T-DMB and 3D DMB video applications including BIFS-based interactive data service. The system is fully backward compatible with the existing T-DMB system. The delivery of 3D video is in-band transmission guaranteeing the monoscopic 2D video service. The extension for 3D video transmission requires 30~50% bitrate overhead. So far, there is no operating service in Korea, however, plans for launching a commercial 3D DMB service via satellite DMB network have been put in place. Concerning standardisation activities, the Telecommunication Technology Association (TTA) of Korea [97] approved last year a 3D DMB data service specification ***(****Digital Multimedia Broadcasting (DMB) Video-Associated Stereoscopic Data Service, TTAK.KO-07.0064****)*** [98].

In the area of commercial satellite broadcast, BSkyB and Eutelsat have been working toward delivery of stereo video. In the end of year 2008, BSkyB has announced a prototype system for 3D video delivery to a 3D display using a HD satellite set-top box [103]. The display however requires glasses. Similar service has been demonstrated by Eutelsat [104]. Stereo video has been transmitted over the EUROBIRD™ 9A satellite channel in half-HD per view, side-by-side, thus occupying the full HD resolution. The imagery can be displayed e.g. on the Hyundai 3D displays utilizing polarized light and the corresponding glasses and equipped with an engine capable of rendering stereo video out of two views side-by-side packed into an HD frame [105].

Four consumer electronics manufacturers demonstrated 3D systems at the Consumer Electronics Show in January 2009 in Las Vegas [117]. LG, Samsung, Sony and Panasonic showed TV sets where left and right views are time interlaced to be watched with shutter glasses. Panasonic has demonstrated also a 3D Full-HD Plasma Theater System having 101'' TV set to display stereo content compressed and stored on a Blu-ray device [118].

4 Research

In this section, we describe research works and projects relevant to the scope of the MOBILE3DTV project.

4.1 Projects

4.1.1 FP7 projects

A number of FP7 3D-related projects are related to the research and technology being developed within the Mobile3DTV project. These projects have been meeting to exchange ideas, to form a vision and to find areas of join collaboration under the umbrella of 3D Media Cluster [69]. We briefly review some of the projects for their relevance to the Mobile3DTV research topics.

One project, targeting 3D technology on mobile devices is *3DPHONE* [70]. It develops an *all-3D* phone, which means that all menus, applications and programs interfaces will have a 3D appearance and shall be perceived in 3D via stereo display technology. Two target platforms will be used to present a broad spectrum of 3D-based Computer Graphics technologies: one platform is the OMAP device with less processing power and limited display technology, which will boil down to stereoscopic displays. The second platform is the UMPC, which has more processing power and allows for high level graphics rendering, like practical engines and complex shading. In the past year, complex video coding and rendering technology was investigated for the UMPC and simplifications investigated for the OMAP device. The latter relates to the the coding technology in Mobile 3DTV and will be closely followed. For the user interface implementation, first functionality was implemented on the OMAP device. As soon as the UI is completed in the following years, it will be of strong interest, since the Mobile3DTV technology could be one specialized application. Both projects develop different aspects for mobile 3D devices and thus nicely complete each other. The two projects have held two bi-lateral meetings: one after the 3DTV-CON 2008, in Istanbul in early June 2008 and the second in parallel with the NEM Summit 2008 in Saint-Malo, France, in September 2008.

In the *3D4YOU* project, the main focus is the development of the 3D transmission chain for home entertainment environments [71]. It targets camera capturing, format conversion from production to transmission/coding format, coding of multiview data and rendering/display. During the past year, new high-definition test material has been recorded. Furthermore, requirements on post-production and formats conversion have been specified. This activity is also relevant to Mobile3DTV, where stereo material for mobile devices is transmitted. Furthermore, last-year developments in 3D4YOU include the investigation of multi-view coding methods for multi-view displays. These methods are of higher-complexity compared to the encoding methods for mobile devices where the low complexity at the decoder is of primary importance and imposes a major restriction. The developed stereo coding methods in Mobile3DTV represent a simplified subset of the set of multi-view coding methods and will be followed. Investigation of human factors and usability is also targeted by 3D4YOU and will be followed as well.

In *3DPresence* project, a multi-party, high-end 3D videoconferencing concept will be developed [72]. In the past year, the acquisition system was specified. Regarding 3D video coding, existing technology will be used and possibly extended with special emphasis on the type of content, namely head-and-shoulder-sequences. This specialization is more computer-graphics based and may include facial animation parameters (FAPs), as specified by the MPEG-4 scene representation. From the display side, lenticular designs for new multi-view displays were investigated. Similar to 3D4YOU, also human factors and usability studies are planned with special emphasis on video conferencing scenarios. In general, the technology developed in 3DPresence has limited relevance for Mobile3DTV.

The *2020 3DMedia* project researches and develops technologies for 3D Digital cinema in the areas of capturing, production, networked distribution and display of sounds and images in 3D [73]. Thus, it targets even larger and more complex systems in comparison to 3D4YOU. In addition to the pure data handling, also metadata descriptions, like annotations or content-based media descriptors as in MPEG-7 are developed. Though large in scale, compared to the 3D video transmission chain for mobile devices being investigated within Mobile3DTV projects, the technologies for capture and content creation and 3D video representation addressed by 2020 3DMedia are followed.

4.1.2 Other projects

ETRI has been very active in developing 3DTV systems and related 3D DMB video applications and services. The related project has been running since 2007. So-far, the research team has developed a 3DTV system, fully backward compatible with the existing DMB system. The project contributed to the national standard, 'Digital Multimedia Broadcasting (DMB) Video-Associated Stereoscopic Data Service', TTAK.KO-07.0064 [98], approved in December 2008 by TTA.

The project will be running till the end of 2010. Currently, a trial system is being developed. In addition, some advanced algorithms and applications of 3D DMB including the enhancement of 3D DMB system chain are being developed [99]. The project targets also the development of an optimal codec and its standardization by a national standard. The standardization process has started in 2007, targeting both national 3D video codec and delivery interface, however at that time the decision has been postponed.

4.2 Research publications

4.2.1 Coding

In the field of classical 2D as well as 3D video coding, numerous papers have been published during the last year. The most important sources are the IEEE Transaction journal series, with the IEEE Transactions on Circuits and Systems for Video Technology as the major representative. Here, a number of comprehensive articles can be found, however since it takes some time for publication, the presented technology is from the year before. Therefore, newer research on these issues can be found in the recent conferences, dedicated to this, which include the IEEE International Conference on Image Processing (ICIP), IEEE International Conference on Multimedia and Exposition (ICME), the Picture Coding Symposium (PCS) and the IEEE 3DTV Conference. We list here most interesting papers and refer to the proceedings of these conferences for details.

Classical field for improvement of 2D video coding are better coding of motion vectors, improvements for the frequency transformation and improved prediction modes. These are also relevant to 3D video coding.

Regarding current and upcoming standards for multi-view source coding, the research carried out in the previous year was partially included into the standard for MVC. Current research focuses strongly on the new 3D Video Coding initiative and also toward free viewpoint video (FVV), since this requires much more fundamental research than pure joint coding of multiple colour sequences as in MVC. For 3D Video Coding, research on better depth estimation techniques [32]-[35], [52]-[59], format representation, like depth-enhanced stereo (DES), multiview video plus depth (MVD), layered depth video (LDV) and the derived specific formats for stereo representation, including 2-view coding, video plus depth and mixed resolution coding. Then, a number of different coding approaches are investigated, which extend state-of-the-art coding [36]-[41], [60]-[68]. Finally, also the rendering or synthesis of intermediate views requires special attention [46]-[51] and new error measures beyond PSNR are required for judging the quality of newly generated views, where no original reference is available [42]-[45]. See research papers [14]-[68].

4.2.2 Error resilience

An overview of error resilience studies addressing DVB-H was provided in deliverable 7.4. Regarding 3D video we refer to two recent studies, which are representative for the main research directions.

In the research article [87], error-resilient stereoscopic streaming system that uses a H.264-based multiview video codec and a rateless Raptor code for recovery from packet losses is explained. A heuristic methodology is suggested for modeling the end-to-end rate-distortion (RD) characteristic of such a system. This model is used to optimally select the parameters of the video codec and the Raptor code to minimize the overall distortion.

Another work studies a scalable MDC scheme for stereoscopic 3D video [88]. MDC is based on separating the even and odd frames into two MDC streams and the error resilience of the base layer of SVC is enhanced by the proposed algorithm. The article reports an improved performance with respect to original SVC.

4.2.3 User studies

In the field of user experience, an important step on defining the term User Experience (UX) and its main concepts has been taken. Law et al. [95] published results of a survey among 275 researchers and practitioners in the field of UX (academia and industry). Until now, the diverse usage of the term user experience has lead to various definitions and concepts about UX. The results of the survey suggest that the draft definition given by ISO DIS 9241-210 “A person's perceptions and responses that result from the use or anticipated use of a product, system or service” is very well in line with the common opinion of the survey participants. Contextual factors are seen to be highly influential and Law et al. suggest focussing on using Use Cases in UX design to assess UX in realistic environments.

In a study about how image quality of stereoscopic content can be measured best, Kuijsters et al. [93] assessed the influence of chroma and depth variations on naturalness and image quality of the stimuli. Their results show that increased chroma values lead to increased scores for naturalness and quality of the stereoscopic content. However, increased depth just leads to increased ratings for naturalness, but image quality has not been affected by depth variations. Kuijsters et al. discuss that image quality is not the only aspect contributing to the concept of naturalness of stereoscopic images.

The understanding of quality factor of stereoscopic images and videos has been addressed in a study by Shibata et al. [96]. Applying interpretation-based quality methodology and combining quantitative and qualitative analysis, Shibata et al. studied the quality experience of stereoscopic content on mobile devices. Their study shows that mobile screens can offer good viewing comfort for 3D content. The cardboard effect [89] was identified as an important quality factor for 3D content. Additionally, the study showed that the small screen size may have impact on feeling of discomfort while watching 3D content.

Shibata et al.'s result outline that visual fatigue (caused by the conflict of vergence and accommodation) is not the only reason for a discomfort feeling. Understanding visual fatigue is still an important research question. Lambooij et al. [94] measured visual discomfort that is associated with stereoscopic displays. In their method they compared optometric tests and self-reporting tools. Their results show that a combination of fusion range measurements and self-report is useful to measure visual fatigue caused by 3DTV.

4.2.4 3D video quality enhancement and quality metrics

Design of 3D video quality metrics is a fairly new research topic and there are only a few very recent papers in the literature. Most of these works start with 2D metrics and try to incorporate information about 3D. In [114], an extension of 2D-metric which involves the measure of the disparity map distortion has been proposed and tested with a methodology for subjective assessment of stereo images.

In [115], comparison of subjective tests and 2D metrics are given for video plus depth represented 3D video. Results show that the output from the VQM objective metric can be mapped, so that it correlates strongly with both the overall viewer perception of image quality and depth perception.

In [116], Stereo Band Limited Contrast (SBLC) metric is proposed for evaluating stereoscopic images under compression. It is based on matching the regions of high spatial frequency between the left and right views of the stereo pair and accounting for HVS sensitivity to contrast and luminance changes in regions of high spatial frequency. Matching algorithm uses SIFT to extract edges, corners and the RANSAC algorithm match the regions.

In [43] a metric is proposed to evaluate depth image based rendering (DIBR) for video plus depth video. It is composed of Colour and Sharpness of Edge Distortion (CSED) measure. Colour distortion measures the luminance loss of the rendered image compared with the reference, and sharpness of edge distortion calculates a depth-weighted proportion of remaining edge to the original edge.

In [42], a rapid method which does not rely on depth map to objectively measure stereo image quality is proposed. The metric has two components: image quality measured by the average of PSNRs of the two views, and stereo sense measured by the absolute difference between the stereo images.

In [44], a metric is proposed for assessing the quality of asymmetrically-coded 3D video. It utilizes a spatial frequency dominance model. The metric is calculated using a weighted sum of differences between degraded and original images and their spatial frequencies' parity deviations.

5 Conclusions

In this report, we have overviewed the state-of-the-art in the area of mobile 3D imaging and video delivery over DVB channels.

The standardization activities related with 3D video coding have been concentrated around the MPEG, where two groups of standards, MVC and 3DV, have been targeted with quite active work during the last year. The transmission of 3D video has caught some interest within the DVB project, where special 3D interest group has been created also last year. The same is valid for the field of objective video quality metrics, where a special interest group within VQEG has been created. User studies have been standardized within ITU-T with the main focus put on quality of experience, mainly for IPTV, videoconferencing, and streaming applications. Mobile and 3D scenarios have not been considered yet. SMPTE has targeted the delivery of stereoscopic imagery to the Home via a variety of channels. Collaboration with other standardization bodies has been explored.

In the area of embedded platforms, the trend has been toward more power and rich media functionality. Decoding of high resolution and high frame rate video seem no problem with the new emerging platforms equipped also with advanced 3D graphics engines. Support of DVB and DMB has been also available. As far as the portable 3D auto-stereoscopic displays are concerned, the trend is to seek commercialization of the cheaper parallax-barrier technology. Devices equipped with such displays have been announced in Japan and Korea. The superior display technology delivered by NEC has been demonstrated by the Mobile3DTV project at a series of exhibitions and raised quite an interest. Little is known about the new OMB technology developed by Toshiba-Matsushita.

We are aware of two experimental end-to-end systems demonstrating mobile 3D television: one functioning at Tampere University of Technology based on DVB-H and built within the Mobile3DTV project and another built by ETRI in Korea, based on T-DMB. The activities in Korea resulted also in a national-wise standard about the 3D DMB data service. Satellite and TV operators have been more interested in 3DTV of higher resolution targeting home entertainment. After the cease of the Philips 3D Solution division, which was developing probably the best-quality large auto-stereoscopic displays (Philips WoW), it seems the short-term trend in the area of 3D home entertainment is to have glasses-enabled 3D displays, while the delivery is done in HD over satellite channels or recorded in Blu-ray format.

The research in the area has been busted by dedicated funding as the 3D Media research topic has been given a priority in the ICT Specific theme of FP7. Group of projects dealing with different aspects of 3D Media have been gathered together within the 3D Media Cluster. This activity is pretty in line with the worldwide trend, clearly seen, i.e. in Korea and Japan, where 3D standardization and commercialization attempts has been progressing quite a bit. Major conferences such as IEEE's ICIP and SPIE's Electronic Imaging have programmed more sessions on related topics where new interesting works have been reported. New scientific events, such as 3DTV-Con, have also taken place to provide forum for presenting and discussing novel research results in the field.

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Mobile 3DTV Content Delivery Optimization over DVB-H System

MOBILE3DTV

MOBILE3DTV - Mobile 3DTV Content Delivery Optimization over DVB-H System - is a three-year project which started in January 2008. The project is partly funded by the European Union 7th RTD Framework Programme in the context of the Information & Communication Technology (ICT) Cooperation Theme.

The main objective of MOBILE3DTV is to demonstrate the viability of the new technology of mobile 3DTV. The project develops a technology demonstration system for the creation and coding of 3D video content, its delivery over DVB-H and display on a mobile device, equipped with an auto-stereoscopic display.

The MOBILE3DTV consortium is formed by three universities, a public research institute and two SMEs from Finland, Germany, Turkey, and Bulgaria. Partners span diverse yet complementary expertise in the areas of 3D content creation and coding, error resilient transmission, user studies, visual quality enhancement and project management.

For further information about the project, please visit **www.mobile3dtv.eu**.

Tuotekehitys Oy Tamlink
Project coordinator
FINLAND

TAMLINK INNOVATION · RESEARCH · DEVELOPMENT LTD

Tampereen Teknillinen Yliopisto
Visual quality enhancement,
Scientific coordinator
FINLAND

Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V
Stereo video content creation and coding
GERMANY

Fraunhofer Institut Nachrichtentechnik Heinrich-Hertz-Institut

TECHNISCHE UNIVERSITÄT ILMENAU

Technische Universität Ilmenau
Design and execution of subjective tests
GERMANY

Middle East Technical University
Error resilient transmission
TURKEY

MULTIMEDIA SOLUTIONS

MM Solutions Ltd.
Design of prototype terminal device
BULGARIA

SEVENTH FRAMEWORK PROGRAMME

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