State of the art of technology and standards

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Abstract: This report reviews the state-of-the-art in the field of mobile 3DTV technologies. We distinguish the following main drivers of that field: standards, systems and research. Standardization activities for representation, coding, transmission, user studies and objective video quality evaluation are reviewed. Commercial DVB-H systems and services are listed, followed by experimental systems for stereo video broadcast over DVB-H. The state of multimedia HW and SW platforms and auto-stereoscopic displays is presented. Relevant research in coding, error resilience, user studies, and video quality enhancement is described. The report makes conclusions about the maturity of different mobile 3DTV technology components and positions the MOBILE3DTV consortium members along the field.

Keywords: mobile 3DTV, MPEG, DVB-H, multimedia platforms, auto-stereoscopic displays
Executive Summary

This report reviews the state-of-the-art in the field of mobile 3DTV technologies. We distinguish the following main drivers of that field: 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 standards in the area. First, we address the standardization activities related with representation and coding of 3D moving scenes. These activities are carried out within the MPEG group. Three relevant standards known as MPEG-C, Part 3, MVC, and 3D VC correspondingly, are briefly reviewed. Second, we address the DVB-H related standardization activities, as this channel is the in the gravitation point of our project. As a new technology, mobile 3DTV has to be studied for its user acceptance. Therefore, we review also relevant standards in the area of user studies and video quality objective measurements.

Section 3 goes from standards to systems. Commercial DVB-H broadcasts (launched and trials) are listed first so to demonstrate the potential of the envisaged market. Experimental systems aimed at stereo video broadcast are reviewed afterwards. The section concludes with review of mobile HW and SW platforms and auto-stereoscopic displays.

Section 4 is about research. It includes works which support, extend or go beyond standardization activities. The review is structured into coding, error resilience, user studies and video quality enhancement, as these are the topics we aim at contributing beyond the existing knowledge and solutions.

In the conclusions section we emphasize the role and position of the consortium members within the field and with respect to the so-reviewed state-of-the-art.

During the preparation of this review, numerous sources of information, including standards, recommendations, HW and SW references, journal articles, conference papers, research and corporate web sites, and news announcements have been used. A representative fraction of 132 sources is listed as references at the end.
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1 Introduction

The MOBILE3DTV project has adopted an evolutionary approach. The novel technology being developed within it has clearly identified components with different levels of maturity. The research on creation, coding, and transmission of mobile stereo video content is based on recent and emerging standards and existing infrastructure. The new technology demonstrator develops on the cutting-edge HW and SW platforms to deliver performance relevant to the comprehensive algorithms and data in terms of speed, memory, and battery consumption. Knowing, following, and competing with the state-of-the-art is crucial for the project success.

In this report, we review the state-of-the-art of the field of mobile 3DTV technologies. We structure it into three main sections: standards, system, and research. First, we review the recent standardization activities related with the coding, transmission, user studies, and quality evaluation of mobile 3DTV content. We start with standardization activities as these are a true measure about what is hot and what is accepted by the community in the field. Further, we provide information about commercial and experimental systems based on DVB-H as to see how standards are put into work. We additionally review the situation with the highly-competing field of mobile HW and SW platforms so to emphasize its role in developing a productive and low-power-consuming device with appropriate form factor. The area of mobile auto-stereoscopic displays is reviewed as well as the display is of decisive importance for the user acceptance of the new technology. Finally we concentrate on more academic oriented research as this is the origin and spring delivering new and fresh ideas and problem solutions for further standardization and practical use. In the conclusions, we emphasize the role and position of the consortium members within this fast growing field.

2 Standards

In this section, we review standards related with representation, coding, and transmission of mobile 3DTV content over DVB-H, as well as with user studies and objective video quality evaluation.

2.1 MPEG activities

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].

2.1.1 MPEG-C, Part 3

The purpose of ISO/IEC 23002-3 Auxiliary Video Data Representations (MPEG-C part 3) is to support all those applications where additional data needs to be efficiently attached to the individual pixels of a regular video. In ISO/IEC 23002-3 it is described how this can be achieved in a generic way by making use of existing (and even future) video codecs available within MPEG.

ISO/IEC 23002-3 consists of an array of N-bit values which are associated with the individual pixels of a regular video stream. These data can be compressed like conventional luminance signals using already existing (and even future) MPEG video codecs. The format allows for optional subsampling of the auxiliary data in both the spatial and temporal domain. This can be beneficial depending on the particular application and its requirements and allowing for very low bitrates for the auxiliary data.

The specification is very flexible in the sense that it defines a new 8-bit code word aux_video_type that specifies the type of the associated data, e.g., currently a value of 0x10 signals a depth map, a
value of 0x11 signals a parallax map. New values for additional data representations can be easily added to fulfill future demands.

The specification is directly applicable to 3D video as it allows specifying such video in the format of single view + associated depth, where the single channel video is augmented by the per-pixel depth attached as auxiliary data. As such, it is susceptible to efficient compression. Rendering of virtual view (at least one in case of stereo) is required at the receiver side.

The specification has been standardized since 2007 [2], [3], [4].

2.1.2 MVC

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.

The video representation format is based on $N$ views. 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.

MVC is to become standard in 2008 (version 1) [5], [6].

2.1.3 3D Video Coding

3D Video Coding (3DVC) is a standard that targets serving a variety of 3D displays. Such displays here in focus present $N$ views (e.g. $N = 9$) simultaneously to the user, so-called multi-view 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 $K$ 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, and a standard is expected in 2010/2011? [7], [8], [9].
2.2 DVB-H developments

The work of digital TV broadcasting standards is carried out within the DVB Project, and the DVB-H standard is presented on the DVB project main site (www.dvb.org). A brief summary of the standard is given on the DVB fact sheets page [37].

The DVB-H specification was standardized by the European Telecommunications Standards Institute (ETSI) in 2004 to achieve IP data broadcasting (“datacasting”) to handheld terminals [38]. Work on the technical specification started in autumn 2002 and was finalised in February 2004; the DVB-H standard was finally published by ETSI (European Telecommunications Standards Institute) as a European Norm in November 2004 [39]. DVB-H adopts the DVB-T physical layer, and introduces certain innovations, both at the physical and (mainly) at the data link layer. DVB-H is optimized for use with battery-powered receivers with internal antennas and small screens. DVB-H supports time-slicing technology, which transmits the broadcast in bursts. The receiver can shut down between bursts, thus saving power significantly. After the standardization, the next step was to validate the technology by means of exhaustive lab and field trials. Such trials have been carried out within the Wing TV project [41]. The main outputs of the project were the validation of the DVB-H suite of Standards, DVB-H equipment and network testing methodology and the update of the “DVB-H Implementation Guidelines”.

From March 2008, DVB-H is officially endorsed by the European Union as the “preferred technology for terrestrial mobile broadcasting” [40].

The DVB-H standard is practically finalized and mobile TV systems and services based on it are being launched (see Section 3). Ongoing standardization work is concentrated on linking with DVB IP data casting (DVB-IPDC) [42].

2.3 Standards in user studies

The studies of user experience have also been guided by several international standards.

2.3.1 ISO standards

The standard ISO 9241-11: Ergonomic requirements for office work with visual display terminals – Part 11: Guidance on usability defines the term usability: “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” This definition of usability is important as it includes the whole system of product, users, and usage contexts to describe usability of products in terms of effectiveness, efficiency and satisfaction which result from using the product. In ISO 9241-11, this viewpoint is included as a framework for specifying and measuring usability of products with respect to description of factors determining the usage context, such as user characteristics or tasks, and introduction of measures, such as efficiency or satisfaction, to describe usability. The standard has been adopted in 1998 [49].

The purpose of ISO 13407: Human-centered design processes for interactive systems, is to introduce human-centered design as a cyclic process with the goal to design usability. ISO 13407 does not focus on explicit method description, but targets the “managing design processes”. Hence, it describes the design process of usability on a level of actions and activities throughout the life cycle of interactive systems. Its goal is to design finally a system that meets user and organizational requirements with respect to users, tasks and usage context. The standard has been operational since [50]. Recently, the standardization activities are focused on revising ISO 13407 to be included in ISO 9241-210 [51].
2.3.2 ETSI HF STF 354

The assessment of the Quality of Experience (QoE) has become more important in audiovisual quality assessment and MOBILE3DTV has started to evaluate user experience for mobile 3D television and video. Within standardization bodies the topic of Quality of Experience has been included into standardization activities. The goal of ETSI HF STF 354 (Specialist Task Force 354 within the Human Factors Group of ETSI) is to provide requirement guidelines for real-time multimedia services aiming at providing a good QoE. Goal is to provide objective and subjective measures of user experience for given communication situations, service prescriptions and levels of QoS [133]. The guidelines as the expression of measure are available in ETSI EG 202 534 [134] and ETSI TR 102 535 [135].

2.3.3 ITU-T SG12

Within the International Telecommunication Union ITU standardization activities towards QoE are targeted in ITU-T SG12, the lead study group on quality of service and quality of experience within the ITU [136]. Goal of ITU-T SG12 to be able to a) measure quality parameters in next generation networks and b) measure their impact on QoE. The challenge of providing good QoE for new multimedia systems is study item of question Q13/12 “QoE, QoS and performance requirements and assessment methods for multimedia including IPTV” [137]. Main study items are the relation of end-user requirements to system parameters and to identify simple and efficient analysis techniques to measure and monitor QoE. All results will be included into the development of new recommendations.

2.4 Standardization activities related with objective metrics

Methods for objective stereo-video quality estimation are very scarce, and have not yet reached the critical mass for comparative studies and standardization procedures. For objective assessment of 2D video quality there is a standardization group formed in 1997, called Video Quality Experts Group (VQEG) [87], which aims at addressing objective metrics for picture and video measurement. VQEG did a comparative study of quality estimation algorithms, which consisted of the following stages – selection of source material, selection of test conditions, subjective tests run in multiple laboratories, objective tests (using the proposes objective measures), and statistical comparison between the subjective and objective data. After analysis of fifteen algorithms in two groups of experiments (Phase I and Phase II), VQEG presented a final report [88]. None of the proposed metric emerged as a clear winner, and one conclusion of the report is that the performance of HVS-based QA metrics leaves considerable room for improvement.

The standardization of stereo-video quality estimation algorithms will probably follow the same steps. Currently an ISO/MPEG group is working on a 3D video standard, and as part of the research of the topic tackles with some issues in stereo-video quality [8]. The workgroup has identified the need of perceptual quality evaluation of 3D video encoded with dense-depth map representation. The perceptual effect of temporal inconsistencies is also to be considered in the future studies by the same workgroup.

3 Systems

In this section, we review critical components of the envisaged mobile 3DTV system. First, we focus on the channel and list commercial and test systems based on DVB-H. Then, we focus on the terminal device and review the state-of-the-art HW and SW platforms, and auto-stereoscopic
displays. The latter two components are likely to be combined in the handheld mobile 3DTV technology demonstrator.

3.1 Real DVB-H broadcasts

Being fairly new technology, first national DVB-H broadcast trials were executed in France (Metz, 2004), Germany (Berlin, 2004), Finland (Helsinki, 2005) and Italy (Turin, 2005). These pilots were aimed to selected groups of tens to hundreds of users. The users were interviewed after the trial period to make consumer surveys. Real national DVB-H broadcasts were then launched in Finland and Italy in 2006. Since then many countries have followed with trials in Europe and worldwide. At the moment (June 2008), national DVB-H broadcasts have been launched in 14 countries worldwide, most recently in Austria and Switzerland related to Euro 2008 football championships. Most of the national services are still free-to-air, however, Italy engaged PayTV model with success. The current situation of national DVB-H broadcasts worldwide including finished (O) and on-going (X) trials and official launches according to DVB-H Global Mobile TV organisation is given at the corresponding web site [89]. We extend the table given there with the periods of trials and launches as in Table 1.
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<td>Stockholm (Viasat)</td>
<td>Trial in 2006</td>
<td>O</td>
</tr>
<tr>
<td><strong>SWITZERLAND</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bern - (Customer Acceptance)</td>
<td>Trial 2006-2007</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Bern - (Technical)</td>
<td>Trial 2005-2006</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Swisscom - Bluewin TV Mobile</td>
<td>LAUNCHED 2008</td>
<td></td>
</tr>
<tr>
<td><strong>TAIWAN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Taichung City - (ChungWha Wideband)</td>
<td>Trial in 2007</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Taipei - (Nokia)</td>
<td>Trial in 2006</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Taipei - (PTS Consortium)</td>
<td>Trial 2006-2007</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Taiwan - Nationwide</td>
<td>TBC</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Experimental systems for stereo-video broadcast

Television broadcasting industry and telecommunications researchers have developed various test systems for transmitting stereoscopic video. These systems range from the analog transmissions of stereoscopic video in anaglyph format of 1960s to the modern digital TV broadcasts. In Japan and Korea, stereoscopic HDTV broadcasting in simulcast and side-by-side formats has been demonstrated at major sports events [106], [107]. MERL has implemented an end-to-end system for live capture, simulcast streaming, and display of multi-view video [108]. Delivery of MVC coded multi-view sequences over IP networks has been studied in [109]. A more thorough survey of these as well as other earlier 3DTV projects has been presented in [110]. Two other projects, which use 3D specific video coding schemes, are described in some more detail below.

In the ATTEST project, backward-compatible delivery of 3DTV was demonstrated on DVB-T system [111]. The 3D video content was represented in the video-plus-depth (2D+Z) format where MPEG-2 coded 2D video is augmented by an MPEG-4 coded depth map sequence. Synthesis of stereoscopic views is done at the receiver side. As a result of this project, format for the depth map related metadata has been standardized as MPEG-C part 3 [112], and the carriage of auxiliary depth map stream within an MPEG Transport Stream has been standardized in an amendment of the MPEG-2 Systems standard [113].

The Korean Electronics and Telecommunication Research Institute (ETRI) has researched the delivery of 3D audio and video content over mobile TV channel based on T-DMB technology. In T-DMB system, which is based on the digital radio standard DAB, the video services are implemented using MPEG-4 technology. Audio and video content in MPEG-4 elementary streams (ES) is synchronized on Sync Layer which is delivered on MPEG-2 TS. The stereoscopic video stream is coded with an H.264/AVC derivative stereoscopic codec and it is displayed on a parallax-barrier type autostereoscopic display. The system retains backward compatibility with 2D T-DMB
by coding the left view video as an independently decodable ES while the right view contains the 3D enhancement information that uses the left view for spatial prediction. The Object Descriptors specify a dependency between the base ES and the enhancement ES. The enhancement ES is given “user private” object type that causes the ES to be ignored by the legacy 2D receivers. The BSAC coded surround audio is delivered as base and enhancement streams which are signalled similarly in Object Descriptors [114], [115].

The research carried out by ETRI has evolved into a project on development of 3D video and 3D data services [126]. By its structure and objectives, this project is very close to the MOBILE3DTV project. The former includes ETRI, as Project Coordinator; TU Media Corp. responsible for pilot tests via satellite DMB; Munhwia Broadcasting Corp. responsible for pilot tests via terrestrial DMB; Net&TV Inc, developing 3D DMB data distribution server; NDIS Corp. developing the 3D DMB display and receiver; and IMusicSoft Corp, focusing on 3D DMB content creation. The project member websites are listed in references [127] - [132].

3.3 Multimedia platforms and displays

3.3.1 Multimedia platforms

There are three big groups of portable multimedia devices:

- **Handheld assistants** - These are the smallest in size and display resolution, with long battery life and usually limited computational power. Personal Digital Assistants (PDAs), Smart phones and Portable Media Players (PMPs) fall in this category. ARM and TI OMAP CPUs are the most commonly used.

- **Ultra Mobile PCs (UMPCs)** – Originally a small form factor PCs, these have a near desktop-class performance, and shortest battery live. UMPC devices include Intel Celeron M, Core Solo or VIA C7-M processors. As they are running desktop operation systems (Windows or Linux), programming for UMPCs benefits from various software development tools available.

- **Portable internet appliances** – According to size and CPU power they fall between handheld assistants and UMPCs. They are designed to be always on-line and are focused on internet and media features. There are two sub-types in this group – Internet Tablets (marketing term used by Nokia [90] and faster Mobile Internet Devices (product family name used by Intel [91]. The devices from Nokia use Linux-based Maemo OS [92], while the Intel leads an effort to create a mobile version of Linux, optimized for its processors [93].

The current state-of-the-art devices in each family are given in Table 2.

ETRI has demonstrated a 3D video and 3D data terminal device based on Sony Vaio UMPC, running Windows and equipped with parallax-barrier auto-stereoscopic display [126]. MasterImage has developed similar device [103].

There are various semiconductor vendors, which compete for the market of low-power, portable multimedia-rich devices. The result is a wide choice of platforms, such as Intel Atom, AMD Geode, the recently announced NVidia Tegra [94], TI OMAP and DaVinci [95], and various ARM-based platforms.
### Table 2. Portable multimedia devices

<table>
<thead>
<tr>
<th>Family</th>
<th>Model</th>
<th>OS</th>
<th>CPU</th>
<th>Display size</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handheld</td>
<td>Archos 705</td>
<td>Linux based</td>
<td>TI DM355</td>
<td>4.3”</td>
<td>800x400</td>
</tr>
<tr>
<td></td>
<td>HTC Advantage</td>
<td>Windows Mobile 6</td>
<td>Marvell @ 624 MHz</td>
<td>5”</td>
<td>640x480</td>
</tr>
<tr>
<td></td>
<td>iPhone</td>
<td>OS X based</td>
<td>S5L8900 @ 412 MHz</td>
<td>3.5”</td>
<td>480x320</td>
</tr>
<tr>
<td></td>
<td>Nokia N95</td>
<td>Symbian</td>
<td>Arm11 @ 332 MHz</td>
<td>2.6”</td>
<td>320x240</td>
</tr>
<tr>
<td>Internet appliance</td>
<td>Nokia N810</td>
<td>Maemo</td>
<td>OMAP 2420 @ 400MHz</td>
<td>4.13”</td>
<td>800x480</td>
</tr>
<tr>
<td></td>
<td>Intel Menlow (2008)</td>
<td>Moblin</td>
<td>Silverthrone @ 1.86 GHz</td>
<td>Various</td>
<td>Various</td>
</tr>
<tr>
<td></td>
<td>Intel Moorestown (2009)</td>
<td>Moblin</td>
<td>Lincroft @ ?</td>
<td>Various</td>
<td>Various</td>
</tr>
<tr>
<td>UMPC</td>
<td>Asus Eee900</td>
<td>Windows/Linux</td>
<td>Intel Atom @ 1.6GHz</td>
<td>8.9”</td>
<td>1024x600</td>
</tr>
<tr>
<td></td>
<td>Samsung Q1 Ultra</td>
<td>Windows</td>
<td>Core solo @ 1.3GHz</td>
<td>7”</td>
<td>1024x600</td>
</tr>
<tr>
<td></td>
<td>Fujitsu LifeBook U810</td>
<td>Windows</td>
<td>Intel A110 @ 800MHz</td>
<td>5.6”</td>
<td>1024x600</td>
</tr>
<tr>
<td></td>
<td>Sony VGN-UX500</td>
<td>Windows</td>
<td>Centrino @ 1.06 GHz</td>
<td>4.5”</td>
<td>800x600</td>
</tr>
<tr>
<td></td>
<td>OQQ-2</td>
<td>Windows</td>
<td>VIA @ 1.6GHz</td>
<td>5”</td>
<td>800x480</td>
</tr>
<tr>
<td></td>
<td>Everun</td>
<td>Windows</td>
<td>AMD Geode LX-900</td>
<td>4.8”</td>
<td>800x480</td>
</tr>
<tr>
<td></td>
<td>Asus Eee701</td>
<td>Windows/Linux</td>
<td>Celeron-M@900MHz</td>
<td>7”</td>
<td>800x480</td>
</tr>
<tr>
<td></td>
<td>HTC Shift</td>
<td>Windows/Windows mobile</td>
<td>Intel Stealey @ 800MHz</td>
<td>7”</td>
<td>800x400</td>
</tr>
</tbody>
</table>
3.3.2 Mobile auto-stereoscopic displays

Mobile 3D displays are designed to fulfil specific requirements. They should be sufficiently small and thin for a handheld device and should provide autostereoscopy – the ability to create 3D effect without requiring glasses. Furthermore, backwards compatibility is a desirable feature – the possibility to switch the display back to “2D” mode, when 3D content is not available. Presently, there are several announced products or prototypes of reconfigurable 3D displays.

A display produced by Sharp uses electronically switchable reconfigurable parallax barrier display based on a patterned retardation film [96]. When the “3D mode” is on, the light passing through the subpixels is selectively blocked, in order different subsets of the screen image to be seen with each eye. These subsets form the “left” and “right” views, respectively. This display has been used to produce the Sharp AL3DU laptops (discontinued). The same parallax barrier has been used for a prototype of portable MVC decoder and player, developed by Nokia Research Center [99].

A reconfigurable 2D/3D technology from Ocuity Ltd. uses a Polarisation Activated Microlens array [97]. The microlens array is made from a birefringent material such that at the surface of the lens there is a refractive index step for only one of the polarisations. A switchable polariser selects either the unrefracted light for 2D displays (i.e. the cylindrical microlens array has no impact) or the refracted light.

A display family announced by NEC provides 2D compatibility by using Horizontally Double-Density Pixels (HDDP) configuration and fixed lenticular lenses. The HDDP configuration is composed of the RGB color arrangement in horizontal stripes with the pixels doubling the horizontal resolution. When the display is to be used in 2D mode, the same image data is written in the two adjacent pixels. With this approach, the 2D/3D switching can be done entirely by software means, and different parts of the displays can be in different modes [98].

Newsight has been marketing 3D displays based on wavelength-selective optical filters and with sizes ranging from 8.4” to 54”. They claim their technology allows also manufacturing portable displays of size of 2” or so [101].

A single user 3D display technology developed by SeeFront utilizes lenticular optical layer mounted in front of a LCD panel. A camera tracks the positions of the eyes so to guide a software module which adaptively fractionizes the stereoscopic views [100]. The optical system can meet design requirements for various size displays including portable displays with small viewing distance. Only 3D viewing mode is provided.

Beside the above reviewed display solutions, auto-stereoscopic displays based either on lenticular optics or parallax barrier technology have been marketed by a number of companies [102] - [105].

4 Research

In this section, we address research efforts which support, employ or go beyond current standards and practical developments. These are interesting as they can provide ideas for our research attempts and basis for comparison.

4.1 Coding

Research related with MPEG-C, part 3 is more or less finished since standardization. Also the potential of additional research is limited. The main objective of previous research was to show the feasibility of the approach and its applicability to stereo transmission in the form of monoscopic video plus accompanying depth. Previous research papers include [10], [11], [12]. More recent research addresses the specificity of depth compression within the framework of 3DVC.
Numerous research has been carried out around coding structures of MVC, as this has been the main standardization effort of 3D video community recently. The research has addressed open questions such as illumination compensation, disparity compensation, view interpolation prediction, view subsampling, and other to obtain better coding performance or less complex coding algorithms (at the expense of coding gain). Most important developments are given in references [13] - [26]. Research on MVC is still ongoing; a number of approaches were finally included into the MVC standard. Overall, the coding efficiency was further improved, although there is the crucial limitation that the data rate is linearly dependent on the number of views. Therefore, research shifts more and more towards 3D Video. This latter activity shows increasing interest in the research community. This includes first papers on depth estimation, view interpolation, and coding of multi-view plus multi-depth. It is expected to increase dramatically through the coming years. In addition, basic research papers also show coding of different 3D vision- and graphics-based representation formats, see [27] - [36].

4.2 Error resilience

Wireless networks are error prone due to factors such as multipath fading and interferences. In addition, the channel conditions of these networks are often non-stationary, such that the available bandwidth and channel error rates are changing over time with large variations. In order to maintain satisfactory QoS, a number of technologies have been proposed targeting different layers of the networks. Among them, error resilient video coding as a technique at application layer tackling transmission errors has gained special interest [44].

At the link layer, DVB-H utilizes Forward Error Correction (FEC). It employs Reed-Solomon (RS) FEC codes encapsulated into Multi-protocol encapsulated sections (MPE-FEC) [38]. The MPE-FEC was also introduced to provide additional robustness required for hand-held mobile terminals. MPE-FEC improves the carrier-to noise (C/N) and Doppler performance in the DVB-H channel while also providing improved tolerance of impulse interference. However, MPE-FEC might fail in the presence of very erroneous conditions. Research efforts have been focused on gathering a-priori knowledge of the transmitted media as to tune the MPE-FEC parameters across the media datagrams to provide better robustness.

While MPE-FEC gives extra error protection for wireless mobile transmission, the standard assumes fix-valued link layer parameters, i.e., fixed code rates in the system. However, a mobile network environment tends to change from time to time, so a static error control scheme that behaves well in one case may become unsuitable in another. A dynamic forward error control scheme (DFEC) that adapts to varying channel conditions has been suggested in [46].
Another trend in research is to study the content of the video to be transmitted and to reorganize it and protect it related with its importance – so-called unequal error protection. Unequal error protection (UEP) is such a scheme that uses a-priori knowledge of the media to differentially protect data using FEC. In UEP, the coded data is divided into layers of different importance. High priority (HP) layers are well protected and low priority (LP) layers are less protected. There are many UEP schemes developed for video streaming. However, only a few deal with the time-sliced DVB-H channel. In [48], analysis of Unequal error protection (UEP) methods related with DVB-H has been done. Various UEP and EEP schemes provided by MPE-FEC in different radio conditions have been compared.

So far, UEP has been studied as an error resilience technique applied to monoscopic video streaming. There are only a few developments aimed at stereoscopic streaming [43] and none particularly tailored for DVB-H channels.

4.3 User studies

While regarding current user studies in the field of 3DTV and especially in the field of mobile TV, one can realize a big change in the field of user-centered design. Additionally to usability, there is the new factor of user experience. Current research has introduced user-centered approaches to study user’s needs and expectations about novel systems and services to better understand the impact of critical components of the system. The cyclic character of user-centered design is standardized in ISO 13407 [57] and ISO 9241-11 [58] provides guidance on usability.

Subjective quality has usually been studied quantitatively based on requirements of the International Telecommunication Union (ITU) [51], [53], [54] offering guidelines to study quality perception studies in controlled, laboratory environments. In the context of mobile television, these studies, which base on quantitative measurements of ITU recommendations, have focused on evaluating the impact of coding errors, low bitrates, and impact of changes in image size or framerates as well as bitrate share between audio and visual modalities [67], [68], [69], [70], [71], [75], [72]. Further, there are studies into transmission errors over DVB-H channel and their impact on the perceived quality [73], [74], but still these studies are rare.

With respect to stereo-coding, there are studies on stereo-coding errors in images and videos [83], [84]. However, user studies in the field of 3DTV have focused more on the impact of different factors on presence, the users feeling of being there. In stereo-video content presentation, the most prominent additional features that influence the perceived quality are depth information [81], [82], perceived sharpness [75] or naturalness (i.e. the most truthful or realistic reproduction of content) [76]. All these factors contribute to the concept of presence, the involvement of the user in the content; the feeling of being there [77]. Nevertheless, some work has reported simulator sickness symptoms caused by the use of stereo-video presentation. This particular impact of stereo vision adversely affects enjoyment and factors creating simulator sickness are not yet known in depth [78].

In contrast to the recommendations of the ITU, current studies in the field of mobile TV include user characteristics, usage contexts and the user’s goal of viewing. Currently there are available results of field trials or studies conducted in several countries [61], [62], [63] as well as results of prospective focus groups [64] and online surveys [65]. In contrast, user studies into the field of 3DTV are still rare and Freeman's focus group [60] is the only study which examines user requirements of 3DTV more broadly.

From the methodological point of view, there is a lot of work in progress to close the shortcomings of ITU recommendations [85]. Researchers have introduces contextual quality evaluation procedure that is conducted in parallel to the controlled laboratory assessments [55]. Additionally,
evaluation of the experienced quality of critical system components targets the future acceptability of the quality of components which were developed in isolation from the end-product [56]. A third step to understand experienced quality is to understand the interpretation of constructed quality and experienced quality factors [79], [80].

Finally, there is one available study into the user experience of mobile 3D television. Following a methodological triangulation of online survey, focus groups and probe study to elicit user requirements, Strohmeier et al. [86] present a broad view on user experience of mobile TV. In all the three studies, they targeted the user experience factors of user, system and services, and contexts. Concluding their study, they present first guidelines to design user experience of mobile 3D television.

4.4 Video quality enhancement

The research in video quality enhancement has been focused on mitigating transform-domain coding effects, such as blocking and ringing or on improvement the quality of the depth map estimated from stereo or multi-view imagery.

All new coding techniques of stereo video are based on H.264 AVC. Correspondingly, they tend to introduce blocking and/or ringing artefacts characteristic for the decorrelating block transform used in the core of the algorithms (i.e. DCT). To deal with these artefacts, de-blocking back-loop filters have been introduced in recent coding standards. Such filters generally improve the motion prediction, while their effect on video quality is rather limited. More powerful schemes have been suggested making use of local and non-local structure analysis of the presented imagery [116], [117], [118]. Such schemes are expected to serve stereo video restoration even better as the over-completeness of the non-local features used for restoration is well presented in the redundant stereo imagery.

While the coding of depth maps is not standardized, it is very likely that it will be utilizing some block-transform based method (e.g. H.264), as compatible hardware, such as DCT chips, is widely available. The blocking effects arising from such compression schemes are well manifested in decoded depth maps due to their nature (gray-scale smooth objects with well-presented edges) and the low bit budget allocated for their coding (10 – 15% of the whole bit budget). Therefore, methods for depth map deblocking become relevant. In addition to already existing deblocking approaches, such methods can benefit from the additional colour video channel presented. Bilateral filtering [119] has been favoured due to its capabilities to filter our artefacts while preserving edges [120].

The depth map deblocking problem is part of the more general depth refinement problem arising from inaccurate depth estimation. One can look at the dissemination activities done by the Middlebury resource web site [121], where the most recent algorithms for depth map from stereo are listed and compared. Most powerful algorithms use post-processing steps to improve the smoothness and fill-in occluded and erroneously-matched areas. This is done by using some kind of colour segmentation of the image channel followed by imposing piece-wise smoothness constraints of the depth channel based on so-obtained segmentation [122], [123], [124]. Yet another problem is related with lower resolution of depth maps arising from multi-sensor depth estimation or very low bit rate compression. Approaches based on super-resolution and aiming at preserving depth map discontinuities have been utilized [125]. More specifically, the input low-resolution depth map is upsampled first to reach the desired spatial resolution. Then, a layered cost volume is constructed and iteratively filtered to obtain more realistic depth estimates.
5 Conclusions
The state-of-the-art review reveals a constantly growing interest to the area of mobile and 3D television technologies. Still, research on optimizing available components for their joint work in a mobile 3DTV system is scarce. Solutions for coding of stereo video are available however it is not clear how these would perform and which one is the best in the case of mobile content. The DVB-H channel is available and it is matter of future research to develop its optimal use for stereo video broadcast. High-performance solutions for monoscopic video restoration exist but those are scarce in the case of stereo video or video plus depth. As of the market of multimedia-rich platforms, it is highly competitive with powerful players there. As an effect, all these companies want to see their platforms running new and cool applications demonstrating the full potential of these platforms and opening new market niches. The choice of platforms is wide and perhaps competing solutions will be available. While the field of auto-stereoscopic displays is constantly growing, there is no ultimately best display. Much is to be done for enhancing the quality of the displayed content as well.

Members of the MOBILE3DTV consortium are well positioned within the reviewed field. Standardization activities of 3D video are led by Fraunhofer. The METU team has pioneered the research in application-layer unequal error protection of stereo and multi-view video. Within the MOBILE3DTV project, the first and pioneering user studies have been carried out jointly by the teams from TUIL and TTY. The signal processing research group from TTY has developed perhaps the best performing image and video restoration algorithms based on strong theoretical fundamental and with application potential. MMS has demonstrated its competence as system integrator by developing mobile imaging modules currently working in 80 mln devices sold around the world. This consortium position compares favourably with respect to the state-of-the-art. However, there is strong competition too. The project described in Sub-section 3.2 and led by Korean ETRI is perhaps the closest and strongest contender. This healthy competition should deliver new technology solutions for the benefit of the targeted users.
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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.