Complete end-to-end 3DTV system over DVB-H

Atanas Gotchev  Stanislav Stankovic  Dominik Strohmeier  Done Bugdayci
Gozde Bozdagi Akar  Heribert Brust  Nikolay Vladimirov
Complete end-to-end 3DTV system over DVB-H

Atanas Gotchev, Stanislav Stankovic, Dominik Strohmeier, Done Bugdayci, Gozde Bozdagi Akar, Heribert Brust, Nikolay Vladimirov

Abstract: This report describes the Mobile3DTV end-to-end system and the final selection of settings for the encoder, transmitter and receiver parts. The choice of settings has been based on the available hardware and software components as well as on the extensive objective and subjective tests carried out during the project. The end-to-end system supports H.264/MVC in base profile (IPPP, 25fps), and provide error protection at application layer by slicing and at link layer by MPE-FEC. Two burst per stereo channel are assumed. Three TV channels are programmed and the corresponding transport streams are pre-recorded and stored at the play-out for continuous streaming, ODFM modulation and broadcasting of baseband signal. The latter is received by the prototype handheld device, which demodulates, decapsulates and decodes streams to play the decoded video on the integrated auto-stereoscopic display. Decoding and playing of stereo videos of nHD resolution at 30 fps is supported by the decoder. Subjective tests have verified the usability of the device and the TV service of the system. The tests have involved 41 participants in a mobile 3DTV use scenario, including free watching of the available three TV channels at spare time in a cafeteria and participating in semi-structured interviews to give answers about the overall quality, system components, use scenario and future use of 3D handheld devices, services and applications. The usability tests have revealed the interest toward mobile 3DTV technology and persisting problems related with the current display technology.

Keywords: Mobile 3DTV, H.264/MVC, MPE-FEC, auto-stereoscopic display, usability
Executive Summary

This report describes the Mobile3DTV end-to-end system and the final selection of settings for the encoder, transmitter and receiver parts. The choice of settings has been based on the available hardware and software components as well as on the extensive objective and subjective tests carried out during the project.

The end-to-end system gets as an input stereo video streams encoded by H.264/MVC in base profile (IPPP, 25fps), and encapsulated in MPE-FEC (2/3 FEC-rate). Two burst per channel are assumed. Three TV program channels are assumed and the corresponding transport streams are pre-recorded and stored at the play-out for continuous streaming, ODFM modulation and broadcasting of baseband signal. The latter is received by the prototype handheld device, which demodulates, decapsulates and decodes streams to play the decoded video on the integrated auto-stereoscopic display. Decoding and playing of stereo videos of nHD resolution at 30 fps is supported by the decoder.

The system is running on a full-scale DVB-H channel covering the university campus of Tampere University of Technology. Low-power versions of the same system are running at the sites of METU, MMS and TUT. The latter has been demonstrated at the ICT Event 2010 in Brussels in May 2010.

Usability tests have been conducted with the aim to test the device and the TV service of the system. The tests have involved 41 participants in a mobile 3DTV use scenario, including free watching of the available three TV channels at spare time in a cafeteria and participating in semi-structured interviews to give answers about the overall quality, system components, use scenario and future use of 3D handheld devices, services and applications. The usability tests have revealed the interest toward mobile 3DTV technology and persisting problems related with the current display technology.

.
Table of Content

1 Overview ........................................................................................................................................... 4
2 Content format and coding ................................................................................................................. 5
3 DVB-H channel ................................................................................................................................. 6
   3.1 Systems ........................................................................................................................................ 6
      3.1.1 Equipment ............................................................................................................................ 6
      3.1.2 DVB-H link layer ................................................................................................................... 6
   3.2 Transmission modes and MPE-FEC setting ................................................................................. 8
4 Terminal device ................................................................................................................................... 10
5 Demonstration of end-to-end MOBILE3DTV system at ICT Event 2010 in Brussels .............. 11
6 Usability tests ..................................................................................................................................... 19
   6.1 Participants ................................................................................................................................ 19
   6.2 Test procedure ............................................................................................................................. 19
      6.2.1 Pre-test and training session ................................................................................................. 19
      6.2.2 Free watching ......................................................................................................................... 19
      6.2.3 Post-test session ..................................................................................................................... 20
   6.3 Test Material and Apparatus ....................................................................................................... 20
      6.3.1 Selection of Test Sequences ................................................................................................. 20
      6.3.2 Selection of Test Parameters ............................................................................................... 22
      6.3.3 Apparatus and Test Setup .................................................................................................... 22
   6.4 Analysis of results ......................................................................................................................... 22
      6.4.1 General quality of the system ............................................................................................... 23
      6.4.2 Quality of 3D content ............................................................................................................. 24
      6.4.3 Perceived Good and Bad Sides of the System ..................................................................... 25
      6.4.4 Usability of System in the Given Scenario .......................................................................... 28
      6.4.5 Additional Scenarios Proposed by Users ............................................................................. 28
   6.5 Conclusion .................................................................................................................................... 31
1 Overview
The final end-to-end system implements the project scenario: stereoscopic video content is captured, properly encoded, encapsulated and then broadcast over mobile TV DVB-H system to be received, decoded and played by a portable device enabled with DVB-H features and integrating an auto-stereoscopic display [1]. The concept is illustrated in Figure 1. At the end of the project, this is not an abstract concept anymore but a block-diagram of a fully-functional system. Encoding algorithms and cross-layer error-protection tools both optimized for mobile use are integrated in the system. A newly developed terminal device connects the content with the users. The design of the system has assumed a user-centered approach and as a result, the system shows a high level of user acceptance. Components, such as device decoders and players and display-related video enhancement tools are ready for commercialization. In the following sections, the building blocks of the system, including encoding, transmission and reception, are presented and the selection of settings is discussed. Demonstration of the system at a European technology event is described. Choice of TV content related with specific user interests is overviewed. Final usability tests of the device and the TV service are presented. The results show a high interest toward the system and positive feedback about its features.

Figure 1: Mobile 3DTV concept
2 Content format and coding

The selected format and coding method supported for the final end-to-end system is H.264/AVC Multi View Coding (MVC) [2]. MVC is characterized by combined temporal and inter-view prediction for motion/disparity compensation. The left view is used as reference for the right view. Prediction has been enabled for anchor as well as for non-anchor frames. No pre- or post-processing is required on the sender or receiver side. Figure 2 shows the general prediction structure of MVC for stereo video.

![MVC coding scheme with stereo video format data: inter-view prediction (red arrows) combined with temporal prediction (black arrows)](image)

Coding has been carried out using the simple baseline profile with the following settings:
- GOP Size: 1 (IPPP)
- Symbol mode: CAVLC
- Search range: 48
- Intra period: 16
- Framerate: 25 fps

The quantization parameter was favorably selected equal to 29 for high quality of the compressed content. Slice mode has been allowed at the encoding stage with size of a slice set to 1000 bytes. This size has been found a good compromise between sufficient resilience in case of error prone channel for acceptable amount of bit rate overhead [2].
3 DVB-H channel

3.1 Systems

3.1.1 Equipment

Two versions of the end-to-end transmission system were built.

At TTY, a full featured transmitter system was setup and used for open air transmissions [Figure 3]. The system consists of proprietary broadcasting equipment and is equipped with 50W power amplifiers and rooftop antennas, covering the campus area with a DVB-H compatible signal. The DVB-H playout server by Cardinal is used for creating timesliced transport streams of A/V content in MPEG-4 files or live IP streams. The transmitted streams can be recorded for future use, which provides means for using the playout server for creating TS files for simulations. Transmitting complete, pre-generated or recorded transport streams is also possible.

![Figure 3 DVB-H Transmitter setup](image)

The DVB-H exciter takes the transport stream as its input and creates an OFDM modulated DVB signal to be broadcasted by the power amplifier and rooftop antenna. Optionally, it is possible to utilize also a diversity unit that prepares the RF signal for two-antenna transmitter diversity broadcasting.

For laboratory experiments and demonstrations, TTY, METU, and MMS also deployed PC based transmitter setups that use a DVB-H modulator card (Dektec DTA-115/DTA-110) for creating the DVB signal [Figure 4]. A set of open-source software tools (FATCAPS, JustDVB-IT) is used for creating the transport stream. The open-source tools offer more flexibility in experimenting with new source/channel coding or content delivery schemes.

3.1.2 DVB-H link layer

At the link layer, the IP datagrams are first read column-wise into the application data table part of the MPE-FEC frame, which consists of a total of 191 columns. The application data table is encoded row-wise using a systematic Reed-Solomon (RS) code; the resulting 64 correction bytes per row are then added to the RS data table part of the MPE-FEC frame. The MPE-FEC code rate (cr) can be adjusted by either zero-padding the application data table, or puncturing the RS data table. After the MPE-FEC frame is constructed, the application data table IP datagrams are encapsulated into MPE sections. In a similar fashion, the RS data table columns are encapsulated into MPE-FEC sections. A stream of MPE and MPE-FEC sections are then put into an Elementary Stream (ES), i.e., a stream of MPEG-2 TS packets with a Particular Program Identifier (PID).

The ESs are time sliced for transmission. The concept of time slicing is to send ESs in bursts using significantly higher bitrate compared to the bitrate required if the data was transmitted
using conventional bandwidth management. Within a burst, the time before the start of the next burst (delta-t) is indicated. Between the bursts, data of the ES is not transmitted, allowing other ESs to use the bandwidth otherwise allocated. This enables a receiver to stay active only for a fragment of the time, while receiving bursts of a requested service, which enables considerable power savings.

**Figure 4 DVB-H Transmitter setup**

In order to realize DVB-H link layer, we used FATCAPS: a Free, Linux-Based Open-Source DVB-H IP-Encapsulator [3]. The FATCAPS implementation builds on JustDVB-IT [4], which is another open source project allowing for establishing a low-cost, highly configurable environment for DVB-T playout as well as possessing a set of tools to create, transform and multiplex MPEG transport streams, and adds the DVB-H specific features. The FATCAPS software reads IP packets, encapsulates in MPE sections and then in MPEG-2 transport stream packets. Finally, the timeslicer component of the software collects the different DVB-H transport streams and multiplexes them using a time division mechanism, so that only one DVB-H stream is seen on the channel at any given time. MPE-FEC sections can be optionally generated and inserted in the stream at this stage in order to provide additional error protection. The final output can be forwarded to a hardware modulator to perform real broadcasting.

In our implementation, we have also modified the FATCAPS software for offline simulation purposes. Current implementation of the software captures IP datagrams from a streamer and encapsulates for transmission in real-time. In our modified implementation, stored IP datagrams can be fed to the software with a given rate and output TS packets can be stored offline. In this way, TS packet losses simulations can be performed.

For research and development work, a PC based receiver has been developed. For this, we use Linux computers equipped with DVB-H/T frontends. Linux operating system has built-in support for decapsulating the IP data in DVB-H transport streams (dvbnet). Alternatively, the streams can be decoded using the Decaps software [5] developed within this project. Compared to dvbnet, it adds several features such as MPE-FEC error correction and collection of error statistics. The IP decapsulator performs the reverse operations of IP encapsulator. It extracts MPE and MPE-FEC sections from the TS. Errors or erasures in the TS can be reliably detected by the CRC-32 code included in each section. The data and RS tables of an MPE-FEC frame are filled with the correctly received sections, and RS decoding is performed to recover the lost data. Integrity of the recovered data finally verified using the UDP checksum. After the error correction, the IP datagrams are fed to the stereo video client, either over a network connection or by saving them to a file. In our system, we implemented the IP decapsulator according to the specifications given in [6], [7]. Video players with RTP support can be used to view the decapsulated broadcasts. The software components of the Linux receiver setup are illustrated in Figure 5.
3.2 Transmission modes and MPE-FEC setting

The physical layer operation of DVB-H is mostly inherited from DVB-T although DVB-H adds a few new features that cannot be used in DVB-T broadcasts [8]. The new DVB-H specific transmission modes include 4K mode, 5MHz bandwidth and in-depth interleaver.

The transmitter operations for creating the DVB-H baseband signal from MPEG Transport Stream (TS) are as follows:

1. Transport stream is randomized and adapted for energy dispersal
2. Outer coder. A shortened Reed-Solomon RS (204,188) code that allows correction of up to 8 erroneous bytes at the receiver is applied to each randomized TS packet
3. Outer (bytewise) interleaver
4. Inner, convolutional coder with code rate of 1/2. The code can be punctured to code rates 2/3, 3/4, 5/6, and 7/8, which provide higher bit rate for application data with the tradeoff of having lower error correction capability.
5. Inner bitwise interleaver and symbol interleaver. The DVB-H specific in-depth interleaving mode can be used instead of the 'native' DVB-T interleaver to gain some additional protection against impulsive interference.
6. The output of symbol interleaver is mapped to the carriers of the OFDM frame according to the constellation in use. If hierarchical modulation is used, it is possible to multiplex two separate transport streams in the high and low priority parts of the broadcast.
7. Pilot and TPS carriers that aid the receiver devices are inserted
8. OFDM
9. Guard interval insertion

There are two coders at the physical layer adding redundant error correction information to the transmission. The MPE-FEC mechanism at the DVB-H link-layer acts as a third, additional layer of protection. The constellation, convolutional code rate and MPE-FEC code rate are the parameters having most significant impact on the channel C/N performance. Simpler constellations (QPSK) are more robust against channel errors than the more complex ones (64-
QAM), stronger FEC codes naturally improve the reception performance under difficult conditions. The Doppler performance is affected also by the OFDM mode [9].

There are altogether five tuneable physical layer parameters: constellation (QPSK, 16-QAM, 64-QAM), OFDM mode (2K, 4K, 8K), code rate of the convolutional coder (1/2, 2/3, 3/4, 5/6, 7/8), inner interleaver mode (native, in-depth), bandwidth (5-8MHz), and guard interval (1/4, 1/8, 1/16, 1/32). Hierarchical transmission mode adds even more alternative ways to construct the broadcast. The large amount of different modulation parameters and their combinations gives flexibility to network planning but makes it more difficult to find the optimal transmission mode.

The following transmission modes have been suggested by previous projects [10]

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Convolutional code rate</th>
<th>MPE-FEC code rate</th>
<th>IP bit rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK 1/2</td>
<td>3/4</td>
<td>3.73</td>
<td></td>
</tr>
<tr>
<td>QPSK 1/2</td>
<td>5/6</td>
<td>4.15</td>
<td></td>
</tr>
<tr>
<td>QPSK 2/3</td>
<td>5/6</td>
<td>5.53</td>
<td></td>
</tr>
<tr>
<td>16-QAM 1/2</td>
<td>3/4</td>
<td>7.46</td>
<td></td>
</tr>
<tr>
<td>16-QAM 1/2</td>
<td>5/6</td>
<td>8.29</td>
<td></td>
</tr>
<tr>
<td>16-QAM 2/3</td>
<td>5/6</td>
<td>11.06</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Recommended DVB-H transmission modes

If high-speed reception (Doppler frequency 80Hz) is desired, only the QPSK modes and 16-QAM with convolutional code rate ½ provide adequate performance. Additionally, studies showed that, at low Doppler frequencies, also the 64-QAM mode with code rate (2/3, 5/6) could provide acceptable quality. As a rule of thumb, they suggested that when choosing the code rates for the convolutional coder and MPE-FEC, the best overall performance can be achieved by spending most of the redundant data in the convolutional coder and using relatively weaker RS code for the MPE-FEC. [11], [10].

For the final end-to-end Mobile3DTV system three TV programmes were considered. Therefore, the more robust 16-QAM modulation scheme was selected. The other parameters were set as follows: 2/3 convolutional code rate, 1/4 guard interval, 8K FFT mode and 666 MHz carrier frequency which results in a channel capacity of 13.2 Mbps.

As the channel conditions were considered fairly good, we gave preference to the encoder with higher quality. In the transmission strategy of two layers (left, right views), we opted for an Equal Error Protection (EEP) scheme using RS(191,256) [12].
4 Terminal device

The prototype handheld device being terminal of the system comprises the following features:

- Processing platform based on OMAP3621, 2GB LP-DDR, 16GB eMMC;
- NEC Stereoscopic Display Module
- DVB-H receiver chip

The characteristics of the autostereoscopic module are as follows:

- Display type: transmissive 3D;
- Number of pixels: 640x360 pixels
- Display size: 3.1 inches diagonal;
- Pixel arrangement: HDDP

The device is capable of receiving the DVB-H modulated baseband signal and demodulating it to transport streams which are then decapsulated and fed to the decoder. The decoder supports base profile of MVC and is capable to decode stereo videos with 640x360 resolution at 30 fps.

Figure 6 shows the final formfactor of the device.

Figure 6 Mobile3DTV terminal device
5 Demonstration of end-to-end MOBILE3DTV system at ICT Event 2010 in Brussels

The MOBILE3DTV was selected as exhibitor at the ICT event 2010 in Brussels. The project’s booth was located in the “Content & Knowledge Zone”. The concept of the booth that was developed within the project consortium was a presentation of a first end-to-end system of 3D content delivery optimization over DVB-H. Fig. presents the preliminary design and idea about the booth. The system is presented in stages and the project tasks regarding these stages are presented in parallel. For each stage, an expert sent by the task-leading partner within the consortium would be present at the booth.

The core of the booth was the demo of the first MOBILE3DTV end-to-end system including a DVB-H transmission of 3D content to the current version of the prototype developed within the project. Within the demo, the visitors at the booth could follow the whole chain of the system from the provider including available contents of different genres and content creation, optimized stereo video encoding methods and error resilient transmission, to the receiver side including visual optimization, 3DTV handheld devices. Finally, all visitors were able to become real users in the user experience stage in which they were able to experience mobile 3DTV on the first available project prototypes.
Figure 8 shows the arrangement of the visual presentations. The programme of the day informed the visitors about was broadcast each day of the exhibition so they could turn on their devices and watch the corresponding channel.

Beyond the overall demo of the system, specific information and small demos for each stage of the production chain were presented on additional mobile 3D video devices. The specific demos demonstrated different coding approaches like MVC or the Video+Depth approach or simulated different transmission artifacts or error resilience strategies so that visitors at the booth were able to see the challenges for which the MOBILE3DTV project provided technological and methodological solutions.
MOBILE3DTV

D6.8 Complete end-to-end 3DTV system over DVB-H

Error Resilient Transmission

- Error Resilience in Video Coding Layer (VCL) via Slice Encoding
- Network Packetization thru RTP/UDP/IP encapsulation of MPEGs
- Representation of two views or 2D video and depth map in separate streams
- Protection over RTP (Application Layer FEC)
- DVB-H transmission medium
- Multi Protocol Encapsulation (MPE)
- Time slicing and MPEG-FEC
- Multiplexing of several IP streams
- Equal Inequality Protection Strategies for MVC and V+D representations
- Transmission in two different faults
- Backward Compatibility

Visual optimization

Importance of depth cues vs. distance
Nomenclature of 3D artefacts

Removal of blocking artefacts in compressed depth maps

Interested in more information, then don't hesitate to ask:

Middle East Technical University
Department of Electrical & Electronics Engineering
Multimedia Research Lab
Döne Bozdag Akar

TAMPEREEN TEKNIILINEN YLIOPISTO
Atanas Boev, Saku Jurnisko-Pyykkö
Figure 8 Posters at the MOBILE3DTV booth at the ICT Event 2010.
Figure 9 Overall outlook of the MOBILE3DTV booth at the ICT Event 2010.
Figure 10 MOBILE3DTV prototype demonstrator at the ICT Event 2010.
Characteristics of the selected contents of the programme of the day

\[ V_{SD} = \text{visual spatial details}, \ V_{TD} = \text{temporal motion}, \ V_D = \text{amount of depth}, \ V_{DD} = \text{depth dynamism}, \ V_{SC} = \text{amount of scene cuts} \]

<table>
<thead>
<tr>
<th>Screenshots</th>
<th>Genre and their audiovisual characteristics</th>
</tr>
</thead>
</table>
| ![Animation - Knight's Quest 4D](image1) | **Animation – Knight’s Quest 4D**  
*Red Star Studio Ltd.*  
*Autor: Benjamin Smith*  
- \( V_{SD} \): med, \( V_{TD} \): high, \( V_D \): high,  
- \( V_{DD} \): high, \( V_{SC} \): high |
| ![Animation - Skull Rock](image2) | **Animation – Skull Rock**  
*Red Star Studio Ltd.*  
*Autor: Benjamin Smith*  
- \( V_{SD} \): high, \( V_{TD} \): high, \( V_D \): med,  
- \( V_{DD} \): med, \( V_{SC} \): high |
| ![Documentary - Heidelberg](image3) | **Documentary – Heidelberg**  
*Dongleware*  
*Autor: Meinolf Amekudzi*  
- \( V_{SD} \): med, \( V_{TD} \): med, \( V_D \): high,  
- \( V_{DD} \): med, \( V_{SC} \): low |
| ![Documentary - TheEye](image4) | **Documentary – TheEye**  
*parallax raumprojektion*  
*Autor: Nikolai Vialkowitsch*  
- \( V_{SD} \): high, \( V_{TD} \): low, \( V_D \): med,  
- \( V_{DD} \): high, \( V_{SC} \): low |
Documentary – Macroshow
DNS Consult
Autor: Günter Peschke

$V_{SD}$: high, $V_{TD}$: med, $V_{D}$: high,
$V_{DD}$: low, $V_{SC}$: low

Sports – 24h Pt.1
KUK Filmproduktion
Autor: Josef Kluger

$V_{SD}$: high, $V_{TD}$: high, $V_{D}$: med,
$V_{DD}$: high, $V_{SC}$: high

Sports – 24h Pt.2
KUK Filmproduktion
Autor: Josef Kluger

$V_{SD}$: high, $V_{TD}$: high, $V_{D}$: med,
$V_{DD}$: high, $V_{SC}$: high

Sports – Skydiving
Dzignlight Studios
Autor: Eric Deren

$V_{SD}$: low, $V_{TD}$: med, $V_{D}$: med,
$V_{DD}$: low, $V_{SC}$: low
6 Usability tests

Usability tests of the prototype device working within the end-to-end mobile 3DTV system were carried out as part of the end-to-end setup. The goal of the tests was to gather knowledge about the perceived quality of the end user experience involving a prototype mobile device for delivery of 3DTV content.

Participants of the test were presented with the prototype Mobile3DTV device with autostereoscopic screen [13]. Content could be selected from three thematic TV channels TV including documentary, cartoon and sport. The test participants were introduced to a possible use scenario and used the device for a period of time. After that they evaluated their experience of the system in their own words, using a set of general question as guidelines.

6.1 Participants

A total of 41 participants who were recruited at Tampere University of Technology took part in the test. In general these users belong to categories of Early Adopters and Early Majority [14]. Those were highly educated, young people where 31 persons were within the age range of 22-28 years and nine were above 29. Participants were not specialists in 3D technology however as students of a technical university they had some understanding of information technologies in general. Participants had little or no experience in qualitative experiments. All participants were screened for normal or corrected to normal visual acuity (myopia and hyperopia, Snellen index 20/30), color vision using Ishihara test, and stereo vision using Randot Stereo test (≥ 60 arcsec).

6.2 Test procedure

The test procedure was divided in four distinct segments, namely a pre-test, a training session, free watching, and a post-test session.

6.2.1 Pre-test and training session

The pre-test and training session took place in the laboratory. In pre-test session, the participants were informed about the nature and the purpose of the test. They were presented with the prototype device and given instructions how to use it. Demographics data was collected during this phase. All volunteers were required to sign an agreement form for the participation in the test, permitting audio and video recording of their responses and informing about the data protection policy.

The participants were screened for myopia, hyperopia, color vision, and stereo vision.

In the training session, all participants watched some high quality stereoscopic videos and played with the device controls to get used to the device and to find a good viewing position for optimal three-dimensional viewing experience.

6.2.2 Free watching

In the test phase participants were supposed to gain the first hand experience using a prototype end device of an end-to-end mobile 3DTV system. The test phase simulated the following scenario.

*The test participant arrives from a lecture and has an appointment with a friend in the café. The friend is late and the participant wants to bridge the time gap and decides to spend the time in the café. He has heard that a new service is available at TUT that he can receive with his new mobile 3D device. The service offers two/three different channels in which 3D content of different type is broadcasted.*
During this phase the participants were able to freely use the prototype device. Devices were receiving stereo videos organizing in three different 3DTV channels. The participants had the opportunity to use the prototype device during a period of 30 - 40 minutes. During this time they could freely choose the channel and to start and stop the playback of the content. They were restricted to use a sofa or a table in the cafeteria indoors with natural light coming from the big windows of the cafeteria and the building. Participants were also free to disrupt the test at any given moment, in case they felt physical discomfort or for any other reason.

6.2.3 Post-test session
A semi-structured interview was carried out after the watching in the cafeteria context. Participants were asked to describe their impressions using their own words, but following a set of general questions as guidelines. Supporting questions were used to ask the participant for detailed explanations of previous answers.

Main Questions:
- How did you experience the general overall quality of the system as a whole as well as of the different channels?
- Did you notice any positive or negative things, things you liked or didn’t like, things that disturbed you or enhanced your experience?
- Which were the quality characteristics you paid attention to?
- How did you experience the scenario and the use of the system in this scenario?
- What kind of thoughts, feelings and ideas have come to your mind while watching about further use scenarios?

Supporting Questions:
- Please, could you describe in more detail, what you mean by X (answer of main question)?
- Please, could you describe in more detail when/how X appeared?
- Please, could you clarify if X was among annoying – acceptable – pleasurable/negative – positive factors?

6.3 Test Material and Apparatus

6.3.1 Selection of Test Sequences
The contents of the three channels were selected in accordance to the user requirements for mobile 3D television and video. Three genres were selected for the channels: Animation, Documentary, and Sports. The different contents have different spatial and temporal characteristics. In addition, all test contents were already used in previous MOBILE3DTV studies in which their general user acceptance was already confirmed.
Table 2: The test contents chosen for the prototype study and their visual characteristics

<table>
<thead>
<tr>
<th>Channel</th>
<th>Screenshot</th>
<th>Genre and their audiovisual characteristics</th>
</tr>
</thead>
</table>
| **Animation channel** | ![Animation channel](image) | ![Animation – Knight’s Quest 4D](image)
*Red Star Studio Ltd.*
*Autor: Benjamin Smith*
*V_{SD}:* med, *V_{TD}:* high, *V_{D}:* high, *V_{DD}:* high, *V_{SC}:* high |
| **Animation – Skull Rock** | ![Animation – Skull Rock](image) | *Red Star Studio Ltd.*
*Autor: Benjamin Smith*
*V_{SD}:* high, *V_{TD}:* high, *V_{D}:* med, *V_{DD}:* med, *V_{SC}:* high |
| **Documentary channel** | ![Documentary channel](image) | ![Documentary – Heidelberg](image)
*Dongleware*
*Autor: Meinolf Amekudzi*
*V_{SD}:* med, *V_{TD}:* med, *V_{D}:* high, *V_{DD}:* med, *V_{SC}:* low |
| **Documentary – TheEye** | ![Documentary – TheEye](image) | *parallax raumprojektion*
*Autor: Nikolai Vialkowitsch*
*V_{SD}:* high, *V_{TD}:* low, *V_{D}:* med, *V_{DD}:* high, *V_{SC}:* low |
| **Documentary – Macroshow** | ![Documentary – Macroshow](image) | *DNS Consult*
*Autor: Günter Peschke*
*V_{SD}:* high, *V_{TD}:* med, *V_{D}:* high, *V_{DD}:* low, *V_{SC}:* low |
6.3.2 Selection of Test Parameters

The video sequences were encoded by MVC [15] with favorable quantization parameter QP=29. The channel settings were selected to be optimal for the anticipated stationary transmission for the cafeteria scenario and the corresponding transport streams were prepared and stored for real-time transmission on the Cardinal play-out. Only 3D viewing mode was supported.

6.3.3 Apparatus and Test Setup

Pre-tests were accomplished in the 3D Media Lab of Tampere University of Technology. The free watching was accomplished in the student café ROM of the TUT campus. The cafeterias in the first floor of the information technology building (Tietotalo) and is used by students and employees weekdays from 8:30 to 17 o’clock. The cafeteria consists of coffee shop, a lounge with comfortable sofas and another area with tables. The same amount of people is normally encountered during the working hours, so the tests were carried out between 9 and 16 o’clock. Participants were given a choice to seat on a sofa or on a table, however the viewing conditions were practically the same since the table and the sofa are close to big windows and face the building entrance. We told the participants to find a good viewing position to have as little as possible light reflections on the display. The background noises were generated by passing by and talking people.

6.4 Analysis of results

The purpose of this test was to gain insight into perceived quality of user experience in relation to end-to-end Mobile 3DTV system. Free-description semi-structured format was designed in order to let the participants formulate their own terminology to describe their impressions about
the proposed system, without imposing preconceived concepts on part of the testers. We were able to bind the terminology extracted from user testimonies into particular properties of the tested system.

In this test we employed the qualitative analysis methodology introduced by Strausss and Gorbin in [16]. This framework is especially well suited for research in areas dealing subjective qualitative assessment, as it is aimed at understanding the meaning or the nature of a person’s personal experience [16].

This methodology consists of following steps:

1. Transcription of audio recordings of interviews,
2. Extraction of meaningful sentence from the original open coded body of text,
3. Extraction of concepts,
4. Categorization of concepts into a hierarchy of classes and subclasses,
5. Calculation of frequencies of occurrence of particular concepts by counting the number of participants which mention them.
6. Review of the results.

If one participant mentioned the same concept in the same context several times, only one occurrence was counted. However, each occurrence in different context was counted separately. Due to the nature of the test, all participants did not provide the feedback on all matters. The percentage calculated represents the part of participants that offered feedback on particular topic, unless indicated otherwise. Based on the answers provided by the participants, we are able to make the following conclusions.

### 6.4.1 General quality of the system

The responses about the general quality of the system are summarized in Figure 11. The majority of participants, 58% of the total number of participants, had a good opinion about the overall system, some using such words as ‘excellent’, ‘outstanding’, and ‘surprisingly good’ to describe their overall experience of the MOBILE3DTV system. Additional 35% of users described the overall quality of the system as satisfactory. Finally, 7% of participants described the system in negative terms, with references like that 3D effect is better perceived on a bid screen than on a small one or that such system is for short-term and not long-term use.
6.4.2 Quality of 3D content

46% of participants described the quality of content as good, 27% as acceptable and additional 27% as bad, as shown in Figure 12.

![Figure 12 Participant opinion on the quality of content.](image)

The percentage of users evaluating the quality of content in positive terms is noticeably smaller than for general quality acceptance of the system. The reason might be that issues with particular parts of content influenced the overall impression. It seems that users see potential in the system, but require the improvement or greater consistency in content quality.
A part of participants 43%, offered feedback about particular types of content. These results are presented in Table 3. Opinions were divided regarding animation channel and in particular documentary channel. The greatest number of users described the documentary channel in positive terms, 36.8%. However, this channel received the greatest number of bad remarks 42%. These results were influenced by the impressions generated by particular scenes. The most neutral impressions were regarding the sports channel. Only 10% of users considered it to be of bad quality, however also only 26.3% described it as good.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Good</th>
<th>No feedback</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animation</td>
<td>26.3%</td>
<td>36.9%</td>
<td>36.8%</td>
</tr>
<tr>
<td>Documentary</td>
<td>36.8%</td>
<td>21.2%</td>
<td>42%</td>
</tr>
<tr>
<td>Sports</td>
<td>26.3%</td>
<td>63.2%</td>
<td>10.5%</td>
</tr>
</tbody>
</table>

Table 3 User content preferences

![Figure 13 User content preferences](image)

### 6.4.3 Perceived Good and Bad Sides of the System

When asked to elaborate in detail the perceived good and the bad aspects of the system users provided more interesting feedback. The majority stated as an obvious advantage the availability of 3D video content on a mobile device. Mobility or portability of the device as an advantage was mentioned by 25% of total participants. Additional 34% participants emphasized to perceived added value in presence of 3rd dimension in video. In addition, 10% of participants stated the freedom of not wearing glasses as a major advantage over competing systems. Bright colours as positive quality were mentioned by 5% of participants. The same number 5% reported the screen size as a positive feature.

As disadvantages of the proposed system the participants have stated several different things. The reported issues can be further classified in several groups.

**Spatial factors** - Compression artefacts were observed by 29% of participants. One user complained about perceived *noise* in HD video on sports channel.

**Disparity** - An amount of 12% of users reported that they were not able to properly *fuse* left and right image to form the illusion of third dimension, under certain circumstances. Regarding the content, as much as 46% of users reported as annoyance the objects that appear to *pop out too much* in front of the screen. They also reported that they were not able to properly focus onto
such objects and that that ruined the impression of 3rd dimension. Additional 10% of users reported unspecified shadows and other artefacts in stereo video.

**Viewing comfort** - major objection by 36% of users was the limited viewing angle and the need to constantly readjust the relative position of the device, associated with the properties of autostereoscopic displays.

**Physical symptoms** - 21% of users reported the eye strain or some other physical discomfort while using the device.

**Form factor** - there was no consensus between users on the size of the proposed device. Some 21% stated that they would prefer a larger display, while significant number of 12% complained that the prototype device is too bulky. Remaining 67% gave no feedback on this matter, as shown in Figure 14.

![Figure 14 Participant opinion on the device form factor.](image)

The summary of perceived positive and negative sides of system is shown in Table 3 and Figure 15.

<table>
<thead>
<tr>
<th>Positive features</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>25%</td>
</tr>
<tr>
<td>Benefit of 3D</td>
<td>34%</td>
</tr>
<tr>
<td>No need for glasses</td>
<td>10%</td>
</tr>
<tr>
<td>Bright colors</td>
<td>5%</td>
</tr>
<tr>
<td>Screen size</td>
<td>5%</td>
</tr>
<tr>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Compression artifacts</td>
<td>29%</td>
</tr>
<tr>
<td>Inability to fuse images</td>
<td>12%</td>
</tr>
<tr>
<td>Blurry objects, objects pop out too much</td>
<td>46%</td>
</tr>
<tr>
<td>Shadows</td>
<td>10%</td>
</tr>
<tr>
<td>Limited viewing angle</td>
<td>36%</td>
</tr>
<tr>
<td>Eye strain</td>
<td>21%</td>
</tr>
<tr>
<td>Screen to small</td>
<td>21%</td>
</tr>
<tr>
<td>Device too big</td>
<td>12%</td>
</tr>
</tbody>
</table>

Table 4 Good and bad sides of the proposed system.

Figure 15 Good and bad aspects of the proposed system
6.4.4 Usability of System in the Given Scenario

The majority of users, 64%, stated that they would definitely use the similar system in the same kind of scenario in real life. Additional 22% might consider using such a device. However, 14% of users are not likely to use this type of device and service in real life, as shown in Figure 16.

![Usability of proposed system in the given scenario](image)

Furthermore, the users who stated that they might consider using the similar system, mentioned the availability and the quality of content as a major determining factor. As additional factor for consideration they also mentioned the possibility to integrate other types of services into the system, aside from streamed stereo video content.

Types of content the users find of interest and possible other applications of autostereoscopic mobile device users discussed more when they were asked to provide other scenarios in which they would like to use the system.

6.4.5 Additional Scenarios Proposed by Users

The users proposed a variety of possible use scenarios for autostereoscopic mobile devices. These scenarios can be grouped in three main categories:

1. Different situations,
2. Particular type of content,
3. Different services.

Greatest number of participants 41.4% mentioned that they would like to use such a device to pass time during travelling. Some of the elaborated the type of vehicle where such a device would be best suited, favouring airplanes and trains over buses. The constant need to readjust the position of the device in reference to limited viewing angle was seen as a potential problem if device was to be used on a bus.
Some 25% of participants commented on the proffered type of content. Their suggestions are presented in Table 5.

<table>
<thead>
<tr>
<th>Type of content</th>
<th>would use</th>
<th>would NOT use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sports</td>
<td>30%</td>
<td>10%</td>
</tr>
<tr>
<td>Documentaries</td>
<td>40%</td>
<td>10%</td>
</tr>
<tr>
<td>Animation</td>
<td>40%</td>
<td>10%</td>
</tr>
<tr>
<td>News</td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>Movies</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>Short clips or user generated content</td>
<td>50%</td>
<td>30%</td>
</tr>
</tbody>
</table>

**Table 5 Types of content suggested by test participants.**

The opinions were most divided when it comes to movies, i.e. full length feature motion pictures, and short clips, which refers to the type of content found on popular video sharing websites, e.g. Youtube. This type of content includes snippets from popular TV shows, movie trailers and user generated content.

Some 50% of users would watch full length movies, especially during travel. However, as much as 40% of users categorically states that they would avoid watching movies on such devices, stating the screen size, or potential physical discomfort as reasons. This number overlaps with users which would prefer shorter content. **Figure 17** shows reported content preferences.

![Figure 17 Types of content suggested by test participants](image-url)
Finally, 34% users have suggested several other possible applications which they would like to see. Table 6 presents the breakdown of possible other applications. Some users have suggested more than one application.

<table>
<thead>
<tr>
<th>Application</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Games</td>
<td>28.5%</td>
</tr>
<tr>
<td>Communications</td>
<td>21.4%</td>
</tr>
<tr>
<td>Internet access or other interactive content</td>
<td>21.4%</td>
</tr>
<tr>
<td>Advertisements</td>
<td>14.2%</td>
</tr>
<tr>
<td>Ability to capture 3D content</td>
<td>21.4%</td>
</tr>
<tr>
<td>Other</td>
<td>21.4%</td>
</tr>
</tbody>
</table>

**Table 6 Types of applications suggested by test participants**

The greatest number 28.5% of users stated that they would like to play games on an autostereoscopic device. In addition, 21.4% would like to have other interactive abilities, i.e. to access Internet using such devices. Significant percent, 21.4% of users mentioned communications, i.e. teleconferencing, as possible application, 14.2% even suggested that they would be interested in seeing product advertisements displayed on autostereoscopic displays, 21.4% of users expressed wish to have an option to capture and create their own content.

Figure 18 shows the types of applications suggested by test participants.
6.5 Conclusion

Based on knowledge gathered by examination of user reports we were able to make several general conclusions. The overwhelming majority of users indicated that they had good or at least satisfactory opinion about the system in general, indicating the clear interest for this type of devices and services. This shows that public perceives the transition of 3D video technology to mobile platform as a next logical step. This step is even seen as imminent by vast majority of participants in the test. Indeed even one of users that gave negative opinion about the system indicated that he did so because at this point he had already taken it for granted.

Furthermore, majority of users expressed the interest in using similar system when available in real-life. The percentage of users that gave positive evaluation of quality of content is a little lower. This indicates the higher level of expectation that users have about the quality of content than about the concept itself. As main positive sides of systems, users indicated the added value of 3D, novelty of 3D, and portability of the device. The relative lack of detail indicates again that users take the future transition of 3D to mobile platform as an obvious necessity. Furthermore, as one of main advantages they cite that system does not rely on glasses to generate the illusion of 3D.

As a principal disadvantage users saw the limited viewing angle which is a property inherent to autostereoscopic display. There is no consensus on the size of the device, main factor being the screen surface. This indicates the more general lack on consensus about mobile devices. Some users value portability of smaller devices which fit into pocket, while others would prefer large screens, such as the ones on table and netbooks.

The major issue regarding content is the length of the provided material. Some users would prefer to watch full-length movies, while others would opt for shorter video clips. This choice is connected with possible discomfort associated whit prolonged watching of stereo video on autostereoscopic displays and also with screen size. Too small screen size is perceived as inadequate for longer content by many users. Shorter video forms are closely associated with user generated content. The ability to make content was also stated as one of desirable feature.
In addition, users see and expect possibilities to combine mobile 3DTV devices with autostereoscopic screens with other technologies. Video games and internet browsing were mentioned as possible applications in prospective communication systems. Users even see autostereoscopic displays as possible advertisement delivery medium, and respond positively to such possibilities.

The elicited results about the final MOBILE3DTV system are very much in line with the user requirements collected at the beginning of the project. The user-centered optimization of the system has provided a well-accepted end-to-end system for users and underlines the possibilities that next mobile devices and related services can offer applying 3D technology.

References

[1] MOBILE3DTV project results, available at www.mobile3dtv.eu/results
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.