Abstract: In this paper, the channel issues of 3D video delivery over DVB-H channel are addressed. The full-scale DVB-H broadcast channel set in Tampere University of Technology is described. In addition, an experimental DVB-H software environment has been built to run extensive channel simulations. The paper summarizes the plan and goals for the simulations and real life experiments to be used for optimizing the 3D video transmission and error protection schemes. Illustrations of channel simulations and field measurements are given.

Keywords: 3D video, broadcast, DVB-H, mobile TV

1 INTRODUCTION

Broadcast of mobile multimedia is becoming a significant factor among mobile network technologies as the amount of mobile multimedia users is increasing. DVB is a standard technology for digital TV broadcasting through terrestrial, cable and satellite networks [1]. DVB-H (Handheld) is its recent extension aimed at mobile broadcasting [2]. The DVB-H standard solutions overcome the challenges of mobile reception environment, by e.g. introducing time-slicing for lower power consumption. DVB-H has been developed to provide broad and flexible broadcast of reach data. As such, it looks quite capable of broadcasting 3D video to mobile users. Similar tests for 3D video broadcasting over T-DMB have been conducted by Electronics and Telecommunications Institute (ETRI) in Korea [17]. In Europe, the topic has been addressed by the MOBILE3DTV project [3] covering topics such as 3D video coding, error resilient transmission, subjective experiments and visual quality enhancement.

Building a DVB-H based channel for 3D video delivery is a key issue and in the very core of the project. Various DVB-H specific questions are being considered. These questions are related to the 3D video representation format, signalling the new content format, simulating the physical channel to develop 3D video specific error resilient techniques and experimenting with delivery over the real channel. It is important to find the optimal format for 3D video representation and coding, would it be two channel stereo, video plus depth or mixed resolution stereo video. Preserving backward compatibility with monoscopic displays is also highly desirable. The delivery of the selected representation format affects the structure of the DVB-H stream.

The MPEG-2 Transport Stream [4] used in DVB-H systems has a flexible IP based structure. The Transport Stream consists of Multi-Protocol Encapsulation (MPE) streams [5] containing IP streams. The elementary streams such as audio, video or other information are carried in the IP streams. This architecture allows for delivering different components of 3D video in separate IP streams or even in separate MPE streams. The form of delivery is strongly related to the signalling of the content of the Transport Stream. In DVB-H, Program Specific Information / Service Information (PSI/SI) [6] inherited from DVB is used for content signalling in low level. Additionally, DVB-H introduced Electronic Service Guide (ESG) [7] for content description and service acquisition. The utilization of PSI/SI and ESG has to be considered when designing potential delivery formats of 3D video.

The use of broadcasting technology relies on physical channel as delivery medium. Especially mobile reception in DVB-H environment is demanding for physical channel, which has to be properly simulated and investigated through experiments. For this purpose, a fully operational DVB-H broadcast environment has been set up at Tampere University of Technology (TUT). The system encompasses the whole broadcast chain including encoder, encapsulator, transmitter and receivers. In addition, a software environment has been built to run physical channel simulations. Various physical channel models have been used to represent different reception conditions. Experimental results in real environments shall be compared with the simulated ones.

In this paper, we explain how 3D video content can be broadcasted to mobile terminal devices over DVB-H channel. We then describe the simulation tools and the real broadcast environment, as well as the simulations and experiments planned to investigate 3D video delivery over DVB-H. Finally, results from simulations and experiments are presented with concluding remarks.
2 DVB-H STREAM STRUCTURE

DVB-H uses MPEG Transport Stream for delivering IP packetized audio and video streams. The IP datagrams are encapsulated within Multi-Protocol Encapsulation sections. From now on, we refer to a sequence of MPE sections having the same Program Identifier (PID) field as an MPE stream [5].

DVB-H specifies an additional error protection mechanism, MPE-FEC (Forward Error Correction) that is implemented in a backward-compatible way on the link layer. The application data table of an MPE-FEC frame is filled column-wise with the IP datagrams. A systematic Reed-Solomon (191, 64) error correction code, which forms the contents of the RS data table part of the MPE-FEC frame, is computed row-wise from the contents of application data table. This RS parity data is read column-wise and encapsulated in MPE-FEC sections that are transmitted after the application data. Use of MPE-FEC is optional. The effective RS code rate can be adjusted by using padding columns in the application data table or puncturing columns in the RS table [20].

The MPE-FEC frame forms also the basic unit of the time-slicing mechanism as all its sections are transmitted consecutively in one burst. Each transmitted section contains the time delta_t until the beginning of the next time-slice of the same MPE stream to be transmitted. This allows the terminal device to switch off the receiver for a short time-slice mechanism as all its sections are transmitted without any ESG extensions. Explicit signalling of all the 3D streams. The monoscopic receivers can completely ignore the 3D video content, while the other stream provides additional information that enables the 3D compatible receivers to render stereoscopic video.

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 loss simulations can be performed deterministically as slight timing differences have no effect on the generated bit streams.

3 DELIVERY OF 3D VIDEO

There are several candidate formats for delivery of 3D video: multi-view coded stereoscopic video, stereoscopic video coded as two independent views, and video augmented with depth data [19]. All of these formats can be transmitted as two separate RTP streams, one of which can be decoded independently by monoscopic legacy receivers, while the other stream provides additional information that enables the 3D compatible receivers to render stereoscopic video.

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The IP decapsulator performs the reverse operations of the IP encapsulator. It extracts MPE and MPE-FEC sections from the TS. Corrupted or missing data of the TS can be reliably detected using the CRC-32 code included in each section. The data and RS tables of an MPE-FEC
frame are filled with the 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.

Lossy channel conditions can be simulated either by using pre-recorded packet loss traces to filter the TS, or by applying some statistical packet loss modelling. A separate Matlab/Simulink tool can be utilized for simulation of the channel at the physical layer [16]. Since the transmitter and receiver side functionalities are separated in different modules, it is possible to flexibly combine parts of the software environment with components of the physical DVB-H transmitter system described in the following section. Similarly, instead of simulating channel losses, it is possible to transmit the software-generated TS over the real DVB-H channel.

4.2 DVB-H Transmitter System

The mobile TV broadcast test bed in TUT consists of realtime encoder, playout system, transmitter, diversity unit, dual antenna system and various receivers. The encoder is employed to create MPEG-4/H.264 coded A/V content for mobile devices. The playout server performs the DVB-H specific IP encapsulation and creates the MPEG-2 [4] Transport Stream for broadcast transmission. The transmitter contains an exciter unit to form DVB signal, and two 50W power amplifiers. The system includes channel filters to guarantee clean signal for the emission. The transmitter components are illustrated in Figure 2. The diversity unit is a specialized device manufactured to execute various diversity profiles. The dual antenna system is located on the roof 25 metres above the ground level. It consists of two vertically polarized omni-directional antennas, which horizontal and vertical separation can be adjusted to examine the effects of the diversity transmission.

![Figure 2: TUT DVB transmitter system components](image)

The models mentioned are used for the 3D DVB-H simulations to represent physical channel. Various transmission parameters and video bitrates are examined to find ideal values or best trade-off between quality and capacity. The basic DVB transmission parameters are constellation (QPSK, 16-QAM, 64-QAM), mode (2k, 4k, 8k), code rate (1/2, 2/3, 3/4, 5/6, 7/8) and guard interval (1/4, 1/8, 1/16, 1/32). The selection of these parameters has a significant effect on signal behaviour in physical channel and therefore, on the quality of reception. This behaviour has already been widely researched, e.g. in Wing-TV [13] and PLUTO [15] projects, and content of transmission has minor effect on it. The 3D DVB-H simulations shall concentrate on various 3D video delivery schemes and applying MPE-FEC on them. Combinations of various 3D video component bitrates and MPE-FEC rates will be simulated.

A Matlab/Simulink [16] tool is used with the DVB-H software to simulate the physical channel. The channel models are implemented with the Matlab/Simulink tool. The Simulink model is built to represent the whole DVB

### Table 1: Definition of PI-channel [14]

<table>
<thead>
<tr>
<th>Path</th>
<th>Delay (μs)</th>
<th>Power (dB)</th>
<th>Doppler Spectrum</th>
<th>Fd (Hz)</th>
<th>STD Nom.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>See table 2</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>-0.4</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
<td>-10.4</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>-103.0</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>-133.3</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>0.9</td>
<td>-137.7</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>-152.2</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>8</td>
<td>1.5</td>
<td>-152.8</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>9</td>
<td>2.1</td>
<td>-149.9</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>10</td>
<td>4.8</td>
<td>-156.2</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>11</td>
<td>9.0</td>
<td>-111.1</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
<tr>
<td>12</td>
<td>9.2</td>
<td>-112.2</td>
<td>Gauss</td>
<td>1.65</td>
<td>0.08</td>
</tr>
</tbody>
</table>

The models mentioned are used for the 3D DVB-H simulations to represent physical channel. Various transmission parameters and video bitrates are examined to find ideal values or best trade-off between quality and capacity. The basic DVB transmission parameters are constellation (QPSK, 16-QAM, 64-QAM), mode (2k, 4k, 8k), code rate (1/2, 2/3, 3/4, 5/6, 7/8) and guard interval (1/4, 1/8, 1/16, 1/32). The selection of these parameters has a significant effect on signal behaviour in physical channel and therefore, on the quality of reception. This behaviour has already been widely researched, e.g. in Wing-TV [13] and PLUTO [15] projects, and content of transmission has minor effect on it. The 3D DVB-H simulations shall concentrate on various 3D video delivery schemes and applying MPE-FEC on them. Combinations of various 3D video component bitrates and MPE-FEC rates will be simulated.

A Matlab/Simulink [16] tool is used with the DVB-H software to simulate the physical channel. The channel models are implemented with the Matlab/Simulink tool. The Simulink model is built to represent the whole DVB...
chain from encoder through physical channel to decoder. Several code blocks respective to DVB modules are implemented both in encoder and decoder side, e.g. RS encoder and DVB modulation mapper in the transmitter part, and demapper and RS decoder in the receiver part respectively. One code block represents the physical channel, where all the channel models are implemented. To run the simulations, randomized data is inputted to the Simulink model, and resulted and input values are compared to calculate Bit Error Rate (BER) and Packet Loss Rate (PLR) in the channel. The results of the simulations will be evaluated by experiments with the real broadcast system in reception environments respective to the simulated models.

6 RESULTS

6.1 Simulations

The Matlab/Simulink tool was originally used to simulate Bit Error Rate (BER) resulted of certain SNR level in the physical channel. For the purposes of 3D video quality simulations, it was enhanced to output Packet Loss Rate (PLR) to represent the percentage of lost TS packets due to physical channel. Resulted PLR is then used in 3D video simulations to see the effect of packet losses on the 3D video quality [18].

The results of the simulations are presented as graphs, where resulted Bit Error Rate (BER) is plotted against Signal-to-Noise Ratio (SNR) in the channel. As the system can be used with two transmitting antennas, it is also taken account in the simulations. Figure 3 shows an example of simulated results in Typical Urban channel. In this simulation, 1-to-1 transmission, transmit diversity, receive diversity cases and the both combined are compared.

In packet loss trace simulations, only 1-to-1 transmission model was used. Amount of data equivalent to be used in video quality simulation was inputted to get comparable results. Initial PLR simulations were performed by using the Typical Urban channel model with transmission parameters QPSK, 8k mode, code rate ½ and guard interval 1/4. Figure 4 shows resulted PLR(%) against SNR in the Typical Urban channel.

![Figure 4: PLR vs SNR in Typical Urban channel](image)

SNR values were selected to be representative with real environment, when some errors appear. Resulted PLR values are also applicable for video simulations [18]. Figure 5 shows BER against SNR in the same simulation.

![Figure 5: BER vs SNR in Typical Urban channel](image)

Comparison of BER and PLR values shows that when reception is considered satisfactory (BER<10^{-3}), PLR<2%, and when reception is considered good (BER<10^{-4}), PLR is already close to 0%.
6.2 Experiments
Experiments in real environment have been performed so far mostly by driving. Moving vehicle represents perfectly the usage profile of DVB-H and varying reception conditions along the route allow analysing the effects of different transmission parameters and MPE-FEC. The 4-km-long route where the measurements were taken is illustrated in Figure 6.

6.2.1 Modulation experiments
In the first experiments, QPSK and 16-QAM modulations were compared. The experiments were performed by driving on the route through suburban and rural areas, averagely 1 km distance from the transmitter. The selected route is located in the area of weak reception, where errors in reception appear. Hence, it is possible to compare error appearance between different transmission parameters.

The route was driven through three times both with 16-QAM and QPSK. The error trace was recorded with a Monitor Station, which calculates the appearance of Reed-Solomon packet errors. The Monitor Station was connected to a GPS device to show recorded errors on the map. The error appearance with similar parameters was consistent, only small amount of variation between each test lap. As expected, significantly fewer errors appeared with QPSK, averagely 30% less. The results are shown in Figures 7 and 8, red dots representing the errors recorded during a representative experiment. In Figure 8, the areas where QPSK modulation performed better than 16-QAM are highlighted.

6.2.2 MPE-FEC experiments
The main emphasis in the experiments was to measure the effect of MPE-FEC. A DVB-H dedicated receiver connected to a laptop equipped with measurement software was utilized. With the receiver and software, it was possible to record Frame Error Rate (FER) and FER after MPE-FEC (MFER) to see the effect of Forward Error Correction. 16-QAM modulation and MPE-FEC 7/8 was used. Several experiments were performed by driving along the test route on four separate days. The results inside test sets were consistent, but variation between test days was noticed. It is due to different weather conditions, which affect noticeably on reception quality. Significant improvement in Frame Error Rate (FER) was noticed when applying MPE-FEC (MFER). Table 2 shows average results of four various test days.
Table 2: FER and MFER

<table>
<thead>
<tr>
<th>Testcast</th>
<th>Reception</th>
<th>FER</th>
<th>MFER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73%</td>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>59%</td>
<td>41%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>81%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>81%</td>
<td>19%</td>
<td>59%</td>
</tr>
</tbody>
</table>

7 CONCLUSION

Delivery of 3D video over DVB-H is a novel research topic carried out by the MOBILE3DTV project. This paper described the process of building the channel for 3D video content over DVB-H including aspects from 3D video coding and delivery, building simulation environment and physical channel models. The experiments performed so far have shown that simpler modulations are more robust against errors, e.g. QPSK vs 16-QAM. Also the use of MPE-FEC significantly improves error resilience. Further simulations and experiments will be done to find recommendable transmission parameter and MPE-FEC values for 3D video delivery over DVB-H also considering capacities needed for the transmitted streams.

8 ACKNOWLEDGEMENTS

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