A Study on the Effect of MPE-FEC for 3D Video Broadcasting over DVB-H

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ABSTRACT

Wireless networks are often error prone due to factors such as multi-path 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. Therefore, they present a challenge for error-resilient video transmission. In order to maintain satisfactory QoS, a number of technologies have been proposed targeting different layers of the networks. DVB-H uses FEC for error protection and comes with an optional FEC tool (MPE-FEC) at the link-layer. In this paper, we propose to use the a priori knowledge of the transmitted media and apply MPE-FEC intelligently to provide better robustness by so-called Unequal Error Protection (UEP) mechanism. Extensive simulation results are given to show the effect of MPE-FEC on 3D compressed video under different channel conditions.

Keywords

DVB-H, stereo video, 3D, error resilient transmission

1. INTRODUCTION

Mobile TV has recently received a lot of attention worldwide with the advances in technologies such as Digital Multimedia Broadcasting (DMB), Digital Video Broadcasting - Handheld (DVB-H) and MediaFLO [7]. On the other hand, 3DTV is a new approach to watching TV, shifting it from being a passive experience to an interactive and more realistic one. With the merge of these two technologies it will be possible to have 3DTV products based on cell phone platforms with switchable 2D/3D autostereoscopic displays in the near future. Currently there are a number of projects
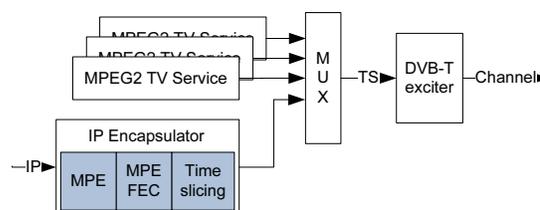
Figure 1: Basic elements of a DVB-H encapsulator and transmitter.

conducting research on this issue such as the Korean 3D T-DMB [4], the European 3D Phone [8] and Mobile3DTV [14]. The latter one, specifically addresses the delivery of 3DTV to mobile users over DVB-H system.

There are several issues which have to be researched for 3D transmission over DVB-H such as the appropriate coding technique, error resilience, display factors etc. In this paper, we try to answer questions related to developing 3D video specific error resilient techniques and experimenting with delivery under different channel conditions. We propose to use the a priori knowledge of the transmitted media and apply MPE-FEC intelligently to provide better robustness by so-called Unequal Error Protection (UEP) mechanism.

The paper is structured as follows. Section 2 briefly summarizes the characteristics of DVB-H. Section 3 presents the experimental mobile 3DTV system used in this study. Section 4 outlines the coding approach used for mobile 3DTV. Section 5 addresses the simulated DVB-H channel. Section 6 analyzes the effect of error protection schemes on 3D video content. Section 7 describes the simulation environment and provides the experimental results together with a discussion. Finally Section 8 concludes the paper.

2. DVB-H

Basic elements of a DVB-H coder and transmitter are shown in Figure 1 [6] [2].

DVB-H is the extension of DVB Project for the mobile reception of digital terrestrial TV. It is based on the existing DVB-T physical layer with introduction of two new elements

for mobility: MPE-FEC and time slicing. Time slicing enables the transmission of data in bursts rather than a continuous transmission; explicitly signaling the arrival time of the next burst in it so that the receiver can turn off in between and wake up before the next burst arrives. By this way the power consumption of the receiver is reduced.

Multi-Protocol Encapsulation is used for the carriage of IP datagram in MPEG2-TS. IP packets are encapsulated to MPE sections each of which consisting of a header, the IP datagram as a payload, and a 32-bit cyclic redundancy check (CRC) for the verification of payload integrity. On the level of the MPE, an additional stage of forward error correction (FEC) can also be added.This technique is called MPE-FEC and improves the C/N and Doppler performance in mobile channels. To compute MPE-FEC, IP packets are filled into an N x 191 matrix where each square of the matrix has one byte of information and N denotes the number of rows in the matrix. The standard defines the value of N to be one of 256, 512, 768 or 1024. The datagram are filled into the matrix column-wise. Error correction codes (RS codes) are computed for each row and concatenated such that the final size of the matrix is of size Nx255. To adjust the effective MPE-FEC code rate, padding or puncturing can be used. Padding refers to filling the application data table partially with the data and the rest with zero whereas puncturing refers to discarding some of the rightmost columns of the RS-data table. The IP input streams coming from different sources are encapsulated and multiplexed for transmission according to the time slicing method. Figure 2 illustrates the MPE-FEC structure.

After encapsulation of IP packets and embedding into MPEG-2 Transport Stream (TS) packets, the next block is the DVB-T modulator. In addition to the 2K and 8K modes of DVB-T, DVB-H also uses an intermediate 4K mode with a 4096-point Fast Fourier Transform (FFT) in the OFDM modulation. The objective of the 4K mode is to improve the network planning flexibility. To further improve robustness of the DVB-T 2K and 4K modes in a mobile environment and impulse noise reception conditions, an in-depth symbol interleaver is also standardized.

3. OVERVIEW OF 3D DVB-H SIMULATION SYSTEM

The building blocks of the system used in this paper are illustrated in Figure 3 [3]. Stereo video content with right and left view is first compressed with a stereo video encoder (joint or simulcast). Resulting Network Abstraction Layer (NAL) units (NALU) are fed to the stereo video streamer. The streamer encapsulates the NAL units into Real Time Transport Protocol (RTP), User Datagram Protocol (UDP) and finally Internet Protocol (IP) datagram for each view separately. The resulting IP datagram are encapsulated in the DVB-H link layer where the Multi Protocol Encapsulation Forward Error Correction (MPE-FEC) and time slicing occurs. The left and right views are assigned different PIDs and encapsulated as different elementary streams. Therefore, left and right views are transmitted in different time slices or bursts. The link layer output MPEG-2 Transport Stream (TS) packets are passed to physical layer where the transmission signal is generated with a DVB-T modulator. After the transmission over a wireless channel, the receiver receives distorted signal and possibly erroneous TS pack-
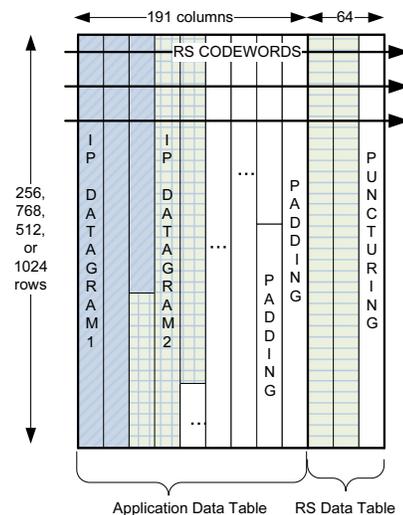

Figure 2: MPE-FEC frame structure.

ets are generated by the DVB-T modulator. The received stream is decoded using the section erasure method,i.e. the MPE-FEC frame is filled with contents of the error-free MPE and MPE-FEC sections and the empty bytes in the frame are marked as erasures, RS decoding is performed to reconstruct the lost data, and finally, the received and correctly reconstructed IP datagram are passed to the video client. IP datagram are handled in the stereo video streamer client and resulting NAL units are decoded with the stereo video decoder to generate right and left views. Finally, these views are combined with a special interleaving pattern to be displayed as 3D in the displayer.

4. STEREO VIDEO CODER

There are a few candidate formats for delivery and storage of 3D video: Simulcast coding, joint coding (Multi-View Coding, MVC), coding as Video-plus-depth (2D+depth) [1]. Hence, there are three main ways to encode these representations. In our system we use both simulcast and joint coding for the experimental study. In the future, these results are planned to be extended to other formats too.

MVC exploits temporal and inter-view redundancy by interleaving camera views and coding in a hierarchical manner. It is an amendment (Amendment 4) to H.264/AVC [12]and not yet completed. First draft is approved in October 2008 and second draft is approved in February 2009. MVC encoder used in our system is JMVM 3.0.2 [11]. Main prediction structure is quite complex introducing a lot of dependencies between images and views. This is valid even if the number of views to be coded is 2 (stereoscopic video). These dependencies make use of the redundancies present in both spatial and temporal directions to reduce the bit rate, however they also impose many restrictions in decoding and packet loss sensitivity. An alternative simplified structure is presented in [9], and shown to be very close to the main prediction structure in terms of overall coding efficiency. In this simplified prediction structure which is used in this study, the temporal prediction using hierarchical B-pictures
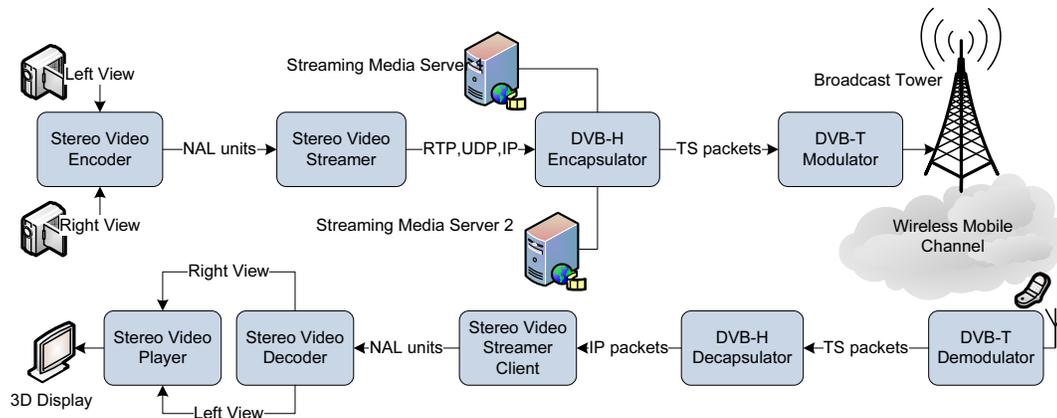
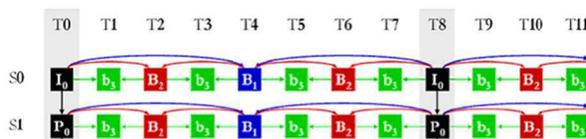Figure 3: Block diagram of the experimental system.

Figure 4: Simplified MVC coding scheme in case of two views.

remains unchanged when compared to original MVC prediction structure, but spatial references are only limited to anchor frames, such that spatial references are only allowed at the beginning of a group of pictures (GOP) between I and P pictures. This simplified version is shown in Figure 4 when the number of views = 2.

5. SIMULATED DVB-H CHANNEL

For simulating the physical transmission channel, we have a MATLAB/Simulink tool [10] that models the DVB-T/H modulation and demodulation processes and the physical transmission channel. The channel is modeled as multipath Rayleigh fading channel with Additive White Gaussian Noise. In this paper a mobile use case with Cost 207 [5] radio channel model TU6, having maximum Doppler frequency of 24 Hz is used to obtain the channel specific error patterns. These patterns are then used for modeling the TS packet loss due to channel conditions. Since TU6 channel suffers more from dispersed errors caused by Doppler shift, the effect of MPE-FEC is more visible on this channel.

The simulations are carried out using the following DVB-H transmission parameters: 16-QAM or QPSK, 1/2 convolutional code rate, 8K OFDM mode, 1/4 guard interval, 8Mhz bandwidth and 3 sec Delta-t. The channel was simulated using SNR levels ranging from 13 dB to 24 dB for 16-QAM and from 9dB to 18dB for QPSK.

6. EFFECT OF MPE-FEC RATE ASSIGNMENT

In [3], the necessity of using MPE-FEC for stereo video broadcasting over DVB-H was shown. In addition, significance of left and right views differ for simulcast and MVC coded videos. Unlike simulcast coding where left and right views have equal priorities due to independent coding; in case of MVC, left and right views possess different priorities. Since the right view is predicted from the left view, any error on the left view will directly affect the quality of the right view also causing a decrease on the overall quality.

The straightforward way to transmit joint or simulcast coded stereo video is to use equal error protection (same MPE-FEC rate) for both left and right views. However, this technique does not utilize the dependency of the views in case of MVC. It is crucial that right view can not be reconstructed regardless of how heavily it is protected or even received with no errors; if the left view is lost. Therefore use of Unequal Error Protection (UEP) between left and right views rather than Equal Error Protection (EEP) seems to be a better strategy for MVC.

We evaluated the impact of MPE-FEC by evaluating different MPE-FEC code rate assignments unequally on left and right sequences. In order to achieve different code rates, we employed puncture and padding operations.

7. EXPERIMENTAL RESULTS

The simulations presented in this paper are carried out using the stereo Horse sequence (480x272, 129 frames, 15 Hz, GOP = 16) prepared by KUK Filmproduktion GmbH and which is available in the stereo video database of Mobile3DTV Project [14].The simulation process was repeated 80 times for each channel SNR condition in order to obtain figures corresponding to the average behavior of the channel. The quality of received and decoded video was measured by computing Y-PSNR and SSIM of the views using original, uncompressed video as the reference. In all the figures, PSNR values are in dB scale and calculated according to the following formulas where D_l and D_r represent the mean squared error in left and right views respectively.

$$PSNR_{joint} = 10 \cdot \log_{10}\left(\frac{255^2}{(D_l + D_r)/2}\right) \qquad (1)$$

$$PSNR_{left(right)} = 10 \cdot \log_{10}\left(\frac{255^2}{D_{l(r)}}\right) \qquad (2)$$

SSIM indices are computed using the following formula [13].

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2cov_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \qquad (3)$$

with μ_x the average of original image; μ_y the average of distorted image; σ_x^2 the variance of original image; σ_y^2 the variance of distorted image; cov_{xy} the covariance of distorted image; $c_1 = 6.5025$, $c_2 = 58.5225$.

Table 1 summarizes different MPE-FEC code rate assignment schemes used in the simulations. For each scheme, the resultant video PSNR and bitrate values after the compression are presented together with the final Transport Stream (TS) bitrate. For all cases, the video is encoded such that the resultant TS bitrate does not exceed the available bitrate defined by the transmission parameters presented in Section 5 with 16-QAM modulation. For example, if a scheme uses stronger FEC protection for a view, then it either reduces the video bitrate or assigns weaker FEC protection for the other view for a fair comparison. During the encoding, we adjust the video bitrate by varying QP values. In the table, EEP-1 and EEP-2 correspond to applying equal error protection to both streams, UEP-1 and UEP-2 correspond to applying different error protection rates to both streams and NO-PRO corresponds to streaming without error protection (MPE-FEC functionality switched off). We simulate simulcast coding with only EEP as the left and right sequences are coded independently.

Before we show the performance of UEP strategy, we first compare simulcast coding and MVC coding using the NO-PRO and EEP-1 schemes shown in Table 1. The average PSNR plots for left view, right view and joint case are shown in Figures 5-7. As seen from the figures, the simulcast case is better only in a few very low channel SNR cases. This can be explained by the fact that in low channel SNR where MPE-FEC protection is not efficient, the frequent losses in left view also affects the right view for MVC case. However, as channel SNR increases, MVC case performs much better than simulcast case.

Next, we compare the different MPE-FEC rate allocation schemes shown in Table 1 for MVC coded video. The average PSNR figures for right view and joint case are shown in Figures 8-9. First of all, the results show a clear improvement of quality when the received MPE-FEC data is used especially in low channel SNR cases together with almost no loss performance for high channel SNR values. When FEC rate increases, again a clear improvement on quality is seen in low channel SNR cases.

Another observation from the Figures 8-9 is that, better quality can be achieved by UEP compared to EEP. This can be seen by comparing EEP-2 and UEP-2. In EEP-2 scheme, both views use a FEC rate of 7/8. In UEP-2 scheme, right view is not protected at all and left view is protected with a FEC rate of 3/4, which is stronger than the 7/8 of EEP-2. Therefore, UEP-2 case is almost equivalent to
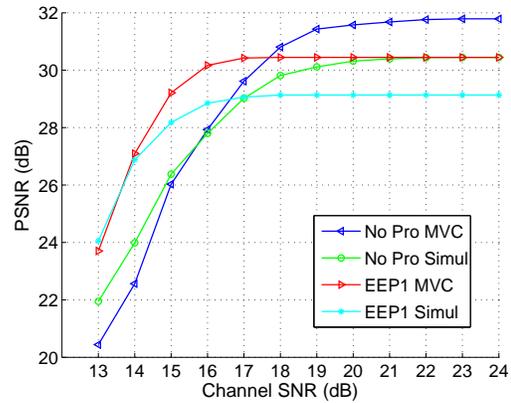

Figure 5: PSNR comparison of MVC and simulcast coding strategies for left sequence. Modulation: 16-QAM
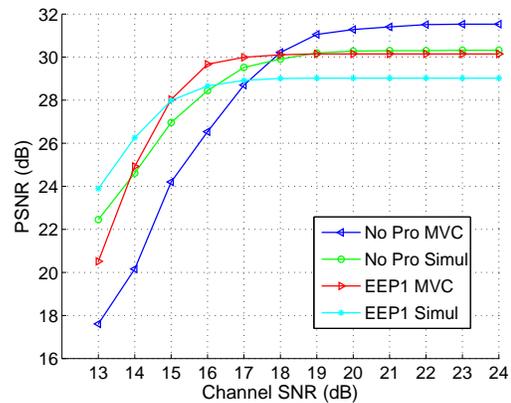

Figure 6: PSNR comparison of MVC and simulcast coding strategies for right sequence. Modulation: 16-QAM
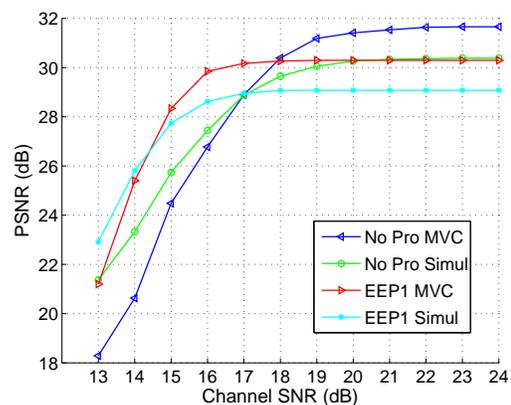

Figure 7: Joint PSNR comparison of MVC and simulcast coding strategies for both sequences. Modulation: 16-QAM

Table 1: Video coding and MPE-FEC rate values used in the simulations with 16-QAM transmission

MVC	FEC Rate		PSNR			Video bit rate (Kbps)			TS bit rate (Kbps)		
	L	R	L	R	Joint	L	R	Total	L	R	Total
NO-PRO	NO FEC	NO FEC	31.79	31.53	31.66	193.25	122.95	316.20	236.62	153.90	390.52
EEP-1	3/4	3/4	30.45	30.15	30.30	143.44	87.62	231.06	235.39	159.67	395.06
EEP-2	7/8	7/8	31.00	30.72	30.86	163.08	101.51	264.59	229.62	151.80	381.42
UEP-1	3/4	7/8	30.45	30.64	30.54	143.44	106.96	250.40	235.39	159.49	394.89
UEP-2	3/4	NO FEC	30.45	31.38	30.89	143.44	139.01	282.45	235.39	173.66	409.05
Simulcast	L	R	L	R	Joint	L	R	Total	L	R	Total
NO-PRO	NO FEC	NO FEC	30.45	30.32	30.38	143.44	143.43	286.87	179.78	179.61	359.39
EEP-1	3/4	3/4	29.14	29.02	29.08	104.68	103.27	207.95	176.11	174.53	350.64
EEP-2	7/8	7/8	29.79	29.67	29.73	123.51	122.43	245.94	178.91	176.63	355.54
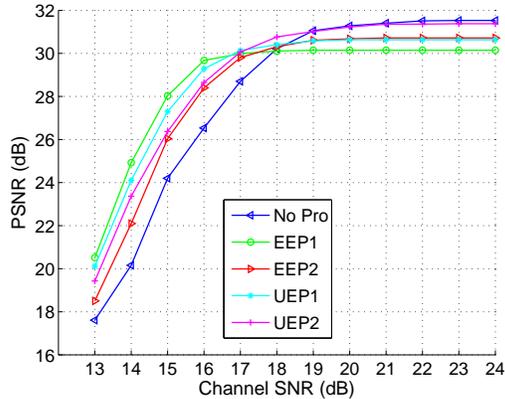
Figure 8: PSNR comparison of MPE-FEC rate assignment strategies for right sequence. Coding: MVC, Modulation: 16-QAM
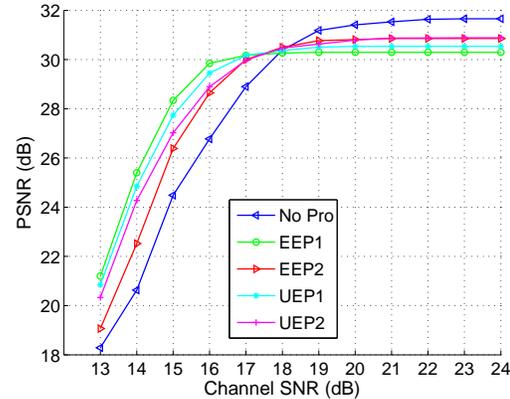
Figure 9: Joint PSNR comparison of MPE-FEC rate assignment strategies for both sequences. Coding: MVC, Modulation: 16-QAM

using parity bits of the right view in EEP-2 for stronger protection of the left view. The figures show that, UEP-2 achieves significant PSNR gains especially in low channel SNR cases. The comparison of EEP-1 and UEP-1 is different from EEP-2 and UEP-2 comparison. The reason is that both EEP-1 and UEP-1 use same FEC protection rate for left view but for right view, UEP-1 method uses the excessive bitrate earned from protecting right view weaker to encode video with a better quality. As a result, EEP-1 performs better in low channel SNR as it employs stronger protection and performs worse in good channel conditions as UEP-1 encodes video with a better quality.

Apart from 16-QAM modulation, we also repeated the same experiments with QPSK modulation. Since QPSK results in half bit rate compared to 16-QAM, we adjust all the video bitrate parameters in Table 1 such that the video bitrates are halved as well. Corresponding parameters are tabulated in Table 2. We show the results of simulcast-mvc coding comparison and different MPE-FEC rate schemes for average joint PSNR case in Figures 10 and 11. The results for QPSK modulation are in agreement with 16-QAM case, confirming our deductions. Comparing the results of QPSK and 16-QAM modulation, QPSK achieves higher PSNR values in very low channel SNR values. This is expected since QPSK is more robust to channel errors than 16-QAM. However, since the data bitrate is halved, maximum quality that

can be achieved by QPSK is much lower than 16-QAM and as the channel conditions get better, 16-QAM performs significantly better.

Finally, we tabulate the results of all the aforementioned experiments in Tables 3-4. The average distortions in Table 3 are given for PSNR values and the ones in Table 4 are given in SSIM metric.

8. CONCLUSIONS AND FUTURE WORK

In this paper, we study the impact of MPE-FEC over the quality of the delivered stereo video for different channel conditions. As shown in the experimental results, although MPE-FEC provides the much needed data robustness for 3D video transmission in wireless channels, under very erroneous conditions it may fail. In order to overcome this we use a priori knowledge of the media to differentially protect data using FEC. High priority (left) video is well protected and low priority (right) video is less protected. The results show that the protection strategy to be used highly depends on the channel conditions. In our future studies we will utilize different priority assignments for better UEP.

9. ACKNOWLEDGMENTS

Table 2: Video coding and MPE-FEC rate values used in the simulations with QPSK transmission

| MVC	FEC Rate		PSNR			Video bit rate (Kbps)			TS bit rate (Kbps)		
	L	R	L	R	Joint	L	R	Total	L	R	Total
NO-PRO	NO FEC	NO FEC	28.56	28.11	28.34	90.08	50.85	140.93	119.62	72.75	192.37
EEP-1	3/4	3/4	27.45	26.94	27.19	79.05	42.91	121.96	120.32	73.28	193.60
EEP-2	7/8	7/8	28.09	27.57	27.83	65.37	35.96	101.33	115.95	74.15	190.10
UEP-1	3/4	7/8	27.45	27.39	27.42	65.37	45.88	111.26	115.95	78.17	194.12
UEP-2	3/4	NO FEC	27.45	27.86	27.65	65.37	57.08	122.45	115.95	79.92	195.87
Simulcast	L	R	L	R	Joint	L	R	Total	L	R	Total
NO-PRO	NO FEC	NO FEC	27.45	27.35	27.40	65.37	64.04	129.41	90.24	88.49	178.73
EEP-1	3/4	3/4	26.53	26.47	26.50	48.67	47.11	95.78	90.24	88.49	178.73
EEP-2	7/8	7/8	27.01	26.94	26.97	57.63	56.26	113.89	91.29	89.37	180.66
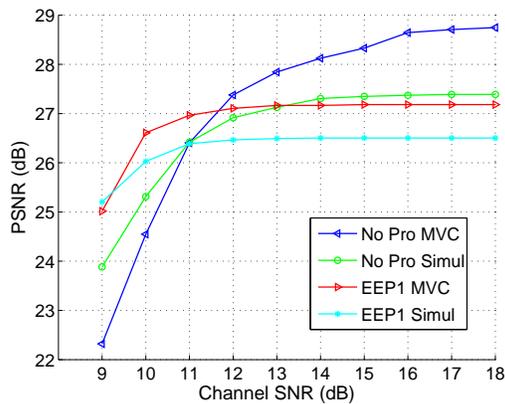
Figure 10: Joint PSNR comparison of MVC and simulcast coding strategies for both sequences. Modulation: QPSK
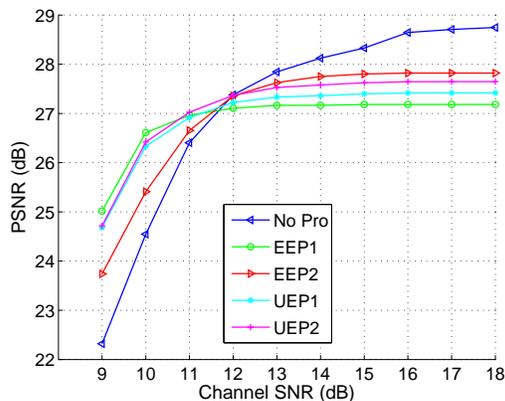
Figure 11: Joint PSNR comparison of MPE-FEC rate assignment strategies for both sequences. Coding: MVC, Modulation: QPSK

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Table 3: Simulation results in average PSNR for 16-QAM and QPSK modulations

Channel SNR	MVC 16QAM					Simulcast 16QAM		
	No Pro	EEP1	EEP2	UEP1	UEP2	No Pro	EEP1	EEP2
13	18.287	21.202	19.069	20.849	20.331	21.369	22.917	21.635
14	20.632	25.402	22.523	24.848	24.273	23.332	25.805	24.037
15	24.483	28.341	26.385	27.739	27.024	25.739	27.743	26.585
16	26.777	29.847	28.644	29.452	28.892	27.445	28.622	28.115
17	28.898	30.170	30.000	30.171	29.973	28.879	28.953	29.031
18	30.387	30.265	30.499	30.368	30.467	29.651	29.070	29.599
19	31.186	30.295	30.766	30.501	30.631	30.052	29.078	29.694
20	31.408	30.295	30.815	30.539	30.787	30.265	29.078	29.718
21	31.533	30.295	30.855	30.539	30.874	30.332	29.078	29.727
22	31.634	30.295	30.855	30.539	30.876	30.364	29.078	29.727
23	31.657	30.295	30.855	30.539	30.888	30.382	29.078	29.727
24	31.657	30.295	30.855	30.539	30.888	30.382	29.078	29.727
Channel SNR	MVC QPSK					Simulcast QPSK		
	No Pro	EEP1	EEP2	UEP1	UEP2	No Pro	EEP1	EEP2
9	22.320	25.017	23.742	24.683	24.718	23.884	25.203	24.442
10	24.549	26.610	25.410	26.335	26.420	25.313	26.028	25.479
11	26.405	26.966	26.655	26.919	27.025	26.418	26.389	26.329
12	27.379	27.105	27.357	27.223	27.368	26.917	26.465	26.716
13	27.844	27.165	27.628	27.333	27.527	27.128	26.492	26.876
14	28.124	27.165	27.752	27.361	27.578	27.305	26.502	26.924
15	28.330	27.182	27.803	27.398	27.623	27.349	26.502	26.969
16	28.646	27.182	27.822	27.416	27.644	27.372	26.502	26.974
17	28.707	27.182	27.822	27.416	27.646	27.388	26.502	26.974
18	28.748	27.182	27.822	27.416	27.647	27.388	26.502	26.974

Table 4: Simulation results in average SSIM for 16-QAM and QPSK modulations

Channel SNR	MVC 16QAM					Simulcast 16QAM		
	No Pro	EEP1	EEP2	UEP1	UEP2	No Pro	EEP1	EEP2
13	0.371	0.495	0.393	0.471	0.457	0.464	0.544	0.481
14	0.474	0.670	0.559	0.656	0.637	0.578	0.677	0.605
15	0.632	0.786	0.711	0.768	0.749	0.692	0.751	0.716
16	0.723	0.840	0.798	0.830	0.813	0.757	0.783	0.774
17	0.801	0.853	0.846	0.853	0.848	0.807	0.794	0.805
18	0.854	0.856	0.864	0.859	0.862	0.833	0.798	0.824
19	0.883	0.857	0.872	0.863	0.867	0.845	0.798	0.827
20	0.889	0.857	0.874	0.864	0.871	0.851	0.798	0.828
21	0.894	0.857	0.875	0.864	0.874	0.854	0.798	0.828
22	0.897	0.857	0.875	0.864	0.874	0.854	0.798	0.828
23	0.898	0.857	0.875	0.864	0.874	0.855	0.798	0.828
24	0.898	0.857	0.875	0.864	0.874	0.855	0.798	0.828
Channel SNR	MVC QPSK					Simulcast QPSK		
	No Pro	EEP1	EEP2	UEP1	UEP2	No Pro	EEP1	EEP2
9	0.522	0.610	0.571	0.603	0.606	0.562	0.582	0.571
10	0.614	0.673	0.643	0.668	0.674	0.621	0.609	0.612
11	0.692	0.687	0.694	0.690	0.697	0.661	0.621	0.642
12	0.731	0.692	0.722	0.700	0.709	0.679	0.624	0.655
13	0.750	0.694	0.733	0.704	0.715	0.686	0.625	0.661
14	0.761	0.694	0.737	0.705	0.717	0.691	0.625	0.662
15	0.772	0.695	0.739	0.706	0.718	0.693	0.625	0.664
16	0.782	0.695	0.740	0.707	0.719	0.693	0.625	0.664
17	0.775	0.695	0.740	0.707	0.719	0.694	0.625	0.664
18	0.774	0.695	0.740	0.707	0.719	0.694	0.625	0.664