Traffic and Quality Characterization of Scalable Encoded Video: A Large-Scale Trace-Based Study
Part 3: Statistical Analysis of Temporal Scalable Encoded Video
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Abstract

In this part we analyze the nearly 110 hours of temporal scalable encoded video in our video trace library. We study the traffic characteristics of the base layer consisting of I and P frames and the enhancement layer consisting of B frames. We also study the video quality provided by the base layer as well as the aggregate (base + enhancement layer) stream. For the encodings without rate control, the base layer is equivalent to extracting the I and P frames out of a single layer encoding, while the enhancement layer is equivalent to extracting the B frames out of the single layer stream. Our statistical analysis provides insights into these layer streams. Our encodings with rate control have a rate-controlled base layer, while the corresponding enhancement layer is encoded without rate control. These encodings are well suited for simulating the widely advocated networking scenario with a nearly constant bit rate base layer and a variable bit rate enhancement layer.

1 Introduction

In this part we conduct a statistical analysis of the video traffic and the video quality for the temporal scalable encoded video. This statistical analysis is based on the terse traces of the base layer and the corresponding enhancement layer. Recall from Part 1 that the terse traces

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give the frame sizes of the individual layers. In addition, the terse base layer trace gives the the qualities (PSNR values) of the luminance component of the base layer stream. The terse enhancement layer trace gives the improvement in the PSNR of the luminance component achieved by the enhancement layer.

2 Analysis of Video Traffic

In this section we analyze the frame sizes (traffic) of the temporal scalable encoded videos. We first study the statistical characteristics of the base layer traffic, then the enhancement layer traffic, and finally the correlations between base layer and enhancement layer traffic.

2.1 Base Layer Traffic

Recall that in the considered Type 1 temporal scalable encodings, the I and P frames constitute the base layer and the B frames constitute the enhancement layer. With the IBBPBBPBBPBBIBB... GoP structure, the frame sizes X^b_{3k+1} and X^b_{3k+2}, $k = 0, \ldots, N/3 - 1$, are zero (as these correspond to "gaps" in the base layer frame sequences). We give the compression ratios, the mean frame sizes ($\bar{X}^b$), the coefficients of variation (CoV^b_X), and the peak-to-mean ratios ($X^b_{\max}/\bar{X}^b$) in Table 1, along with the mean bit rates ($\bar{X}^b/T$), and the peak bit rate ($X^b_{\max}/T$). We define the compression ratio for the base layer as the ratio of the total file size of the uncompressed (YUV) video to the file size of the base layer.

We note by comparing Table 1 with Table 1 in Part 2 that the compression ratios of the temporal base layer without rate control are roughly two to three times larger than the compression ratios of the single layer encodings. (Equivalently, the $\bar{X}^b$ is roughly one third to one half of the $\bar{X}$ in Part 2.) This is reasonable since for every three frames in the single layer encoding there is one frame in the temporal base layer encodings, with the base layer containing the typically large I and P frames.

For the encodings with rate control we observe that the encoder meets all of the specified target bit rates with high accuracy. This is in contrast to the single layer encoding where the encoder was not able to meet the 64 kbps target bit rate. When encoding the base layer, the encoder has to "squeeze" fewer frames into the assigned target bit rate, 4 frames per GoP in the temporal base layer versus 12 frames for the single layer encoding. All of the low quality base layer encodings (which use a quantization parameter of 30) have a mean bit rate below 64 kbps; in fact, the mean bit rates are all below 50 kbps. As a consequence the encoder has "room" to adjust the quantization parameters in their valid range (up to 31) to meet the target bit rate.

Table 1: Overview of frame statistics of the base layer of temporal scalable encoded video

		Compr.	Frame Size			Bit Rate	
Enc. M.	Video	Ratio YUV:BL	Mean $\bar{X}^b$ [kbyte]	CoV CoV_X^b	Peak/Mean $X^b_{\max}/\bar{X}^b$	Mean $\bar{X}^b/T$ [Mbps]	Peak $X^b_{\max}/T$ [Mbps]
QCIF	*Citizen Kane*	38.503	0.987	1.829	17.110	0.237	4.054
H.Q.	*Die Hard I*	29.427	1.292	1.612	10.077	0.310	3.124
No R.C.	*Jurassic Park I*	24.060	1.580	1.688	12.193	0.379	4.624
	Silence of the Lambs	42.495	0.895	1.848	18.463	0.215	3.964
	Star Wars IV	34.697	1.096	1.694	15.975	0.263	4.201
	Star Wars V	24.858	1.529	1.648	10.064	0.367	3.694
	The Firm	30.714	1.238	1.741	13.117	0.297	3.896
	Terminator I	27.487	1.383	1.652	10.590	0.332	3.515
	Total Recall	28.410	1.338	1.630	11.227	0.321	3.606
	Aladdin	16.416	2.316	1.540	9.956	0.556	5.533
	Cinderella	22.015	1.727	1.597	15.166	0.414	6.285
	Baseball with Comm	21.772	1.746	1.556	9.680	0.419	4.056
	Snowboard with Comm	19.162	1.984	1.600	12.966	0.476	6.174
	Oprah w/o Comm	16.732	2.272	1.534	7.226	0.545	3.941
	Tonight Show w/o Comm	29.313	1.297	1.994	13.973	0.311	4.349
	Lecture-Gupta	18.332	2.074	1.523	8.037	0.498	4.000
	Lecture-Reisslein	17.160	2.215	1.607	12.085	0.532	6.426
QCIF	*Jurassic Park I*	70.564	0.539	1.960	16.470	0.129	2.130
H.–M.Q.	*Star Wars IV*	109.007	0.349	2.026	28.651	0.084	2.398
No R.C.	*The Firm*	97.671	0.389	2.148	20.536	0.093	1.918
	Tonight Show w/o Comm	90.407	0.421	2.405	22.473	0.101	2.268
QCIF	*Citizen Kane*	131.133	0.290	2.511	28.996	0.070	2.017
M.Q.	*Die Hard I*	111.003	0.342	2.129	20.138	0.082	1.655
No R.C.	*Jurassic Park I*	90.045	0.422	2.289	21.017	0.101	2.130
	Silence of the Lambs	170.021	0.224	2.561	37.791	0.054	2.028
	Star Wars IV	133.729	0.284	2.296	35.149	0.068	2.398
	Star Wars V	108.101	0.352	2.316	20.388	0.084	1.721
	The Firm	122.171	0.311	2.486	24.636	0.075	1.840
	Terminator I	94.455	0.402	2.088	16.801	0.097	1.623
	Total Recall	109.314	0.348	2.171	19.001	0.083	1.586
	Aladdin	67.034	0.567	2.038	16.478	0.136	2.243
	Cinderella	89.246	0.426	2.128	26.488	0.102	2.708
	Baseball with Comm	95.630	0.398	2.120	19.493	0.095	1.860
	Snowboard with Comm	73.025	0.521	2.084	20.577	0.125	2.571
	Oprah w/o Comm	75.570	0.503	2.178	15.127	0.121	1.826
	Tonight Show w/o Comm	114.692	0.331	2.872	26.495	0.080	2.108
	Lecture-Gupta	76.918	0.494	2.335	18.699	0.119	2.218
	Lecture-Reisslein	74.746	0.509	2.370	20.114	0.122	2.455
QCIF	*Jurassic Park I*	193.233	0.197	1.995	19.051	0.047	0.900
M.–L.Q.	*Star Wars IV*	238.974	0.159	1.987	33.329	0.038	1.272
No R.C.	*The Firm*	245.2329	0.155	2.136	21.081	0.037	0.784
	Tonight Show w/o Comm	261.060	0.146	2.533	30.057	0.035	1.050
QCIF	*Citizen Kane*	298.791	0.127	2.038	21.465	0.031	0.655
L.Q.	*Die Hard I*	232.882	0.163	1.797	16.399	0.039	0.642
No R.C.	*Jurassic Park I*	232.778	0.163	1.881	17.776	0.039	0.697
	Silence of the Lambs	344.986	0.110	1.930	25.936	0.026	0.686
	Star Wars IV	269.274	0.141	1.870	30.309	0.034	1.027
	Star Wars V	251.911	0.151	1.921	17.911	0.036	0.649
	The Firm	285.987	0.133	1.986	18.574	0.032	0.593
	Terminator I	214.775	0.177	1.806	13.740	0.042	0.584
	Total Recall	235.998	0.161	1.814	14.384	0.039	0.556
	Aladdin	179.902	0.211	1.882	16.809	0.051	0.852
	Cinderella	223.681	0.170	1.871	27.054	0.041	1.104
	Baseball with Comm	223.523	0.170	1.818	14.787	0.041	0.604
	Snowboard with Comm	182.722	0.208	1.862	16.601	0.050	0.829
	Oprah w/o Comm	236.059	0.161	1.953	14.716	0.039	0.569
	Tonight Show w/o Comm	322.264	0.118	2.370	29.068	0.028	0.823

Table 1: *continued*

		Compr.	Frame Size			Bit Rate	
		Ratio	Mean	CoV	Peak/Mean	Mean	Peak
Enc. M.	Video	YUV:BL	$\bar{X}^b$ [kbyte]	CoV_X^b	$X^b_{\max}/\bar{X}^b$	$\bar{X}^b/T$ [Mbps]	$X^b_{\max}/T$ [Mbps]
	Lecture-Gupta	221.784	0.171	2.371	20.273	0.041	0.834
	Lecture-Reisslein	224.043	0.170	2.327	24.864	0.041	1.013
QCIF R.C. 64 kbps	*Citizen Kane*	142.459	0.267	2.051	36.983	0.064	2.369
	Die Hard I	142.455	0.267	1.862	35.310	0.064	2.262
	Jurassic Park I	142.452	0.267	1.896	31.337	0.064	2.007
	Silence of the Lambs	142.461	0.267	1.867	26.790	0.064	1.716
	Star Wars IV	142.461	0.267	1.873	54.929	0.064	3.518
	Star Wars V	142.459	0.267	1.830	30.305	0.064	1.941
	The Firm	142.455	0.267	1.987	43.839	0.064	2.808
	Terminator I	142.411	0.267	1.825	59.053	0.064	3.783
	Total Recall	142.461	0.267	1.872	24.886	0.064	1.594
	Aladdin	142.460	0.267	1.799	52.849	0.064	3.385
	Cinderella	142.461	0.267	1.886	70.436	0.064	4.511
	Baseball with Comm	142.461	0.267	1.827	51.579	0.064	3.303
	Snowboard with Comm	142.458	0.267	1.782	51.473	0.064	3.297
	Oprah w/o Comm	142.459	0.267	1.952	39.291	0.064	2.516
	Tonight Show w/o Comm	142.461	0.267	2.010	25.501	0.064	1.633
	Lecture-Gupta	142.461	0.267	2.359	27.854	0.064	1.784
	Lecture-Reisslein	142.460	0.267	1.898	81.678	0.064	5.231
QCIF R.C. 128 kbps	*Citizen Kane*	71.255	0.534	1.799	12.022	0.128	1.539
	Die Hard I	71.253	0.534	1.683	11.343	0.128	1.452
	Jurassic Park I	71.255	0.534	1.746	11.420	0.128	1.462
	Silence of the Lambs	71.255	0.534	1.674	12.573	0.128	1.610
	Star Wars IV	71.255	0.534	1.675	11.096	0.128	1.421
	Star Wars V	71.255	0.534	1.659	10.598	0.128	1.357
	The Firm	71.254	0.534	1.775	13.070	0.128	1.674
	Terminator I	71.255	0.534	1.663	10.290	0.128	1.318
	Total Recall	71.255	0.534	1.690	12.886	0.128	1.650
	Aladdin	71.255	0.534	1.674	18.772	0.128	2.404
	Cinderella	71.255	0.534	1.689	16.920	0.128	2.166
	Baseball with Comm	71.255	0.534	1.645	10.753	0.128	1.377
	Snowboard with Comm	71.256	0.534	1.674	12.721	0.128	1.629
	Oprah w/o Comm	71.255	0.534	1.773	11.700	0.128	1.498
	Tonight Show w/o Comm	71.255	0.534	1.819	12.339	0.128	1.580
	Lecture-Gupta	71.255	0.534	1.925	9.805	0.128	1.255
	Lecture-Reisslein	71.255	0.534	1.768	10.631	0.128	1.361
QCIF R.C. 256 kbps	*Citizen Kane*	35.634	1.067	1.594	11.664	0.256	2.987
	Die Hard I	35.633	1.067	1.532	10.525	0.256	2.695
	Jurassic Park I	35.633	1.067	1.584	10.033	0.256	2.569
	Silence of the Lambs	35.634	1.067	1.524	10.616	0.256	2.718
	Star Wars IV	35.634	1.067	1.526	9.582	0.256	2.454
	Star Wars V	35.634	1.067	1.525	9.987	0.256	2.557
	The Firm	35.634	1.067	1.575	11.423	0.256	2.925
	Terminator I	35.634	1.067	1.524	9.888	0.256	2.532
	Total Recall	35.634	1.067	1.534	9.981	0.256	2.556
	Aladdin	35.634	1.067	1.526	8.504	0.256	2.177
	Cinderella	35.634	1.067	1.535	9.949	0.256	2.547
	Baseball with Comm	35.634	1.067	1.518	9.506	0.256	2.434
	Snowboard with Comm	35.634	1.067	1.534	10.404	0.256	2.664
	Oprah w/o Comm	35.634	1.067	1.589	10.173	0.256	2.605
	Tonight Show w/o Comm	35.634	1.067	1.617	9.687	0.256	2.480
	Lecture-Gupta	35.634	1.067	1.608	8.363	0.256	2.141
	Lecture-Reisslein	35.634	1.067	1.560	7.014	0.256	1.796

For the encodings without rate control we observe again a significant peak in the variability (both in terms of CoV_X^b and $X^b_{\max}/\bar{X}^b$) for encodings at the medium quality level. In addition, the high quality base layer has somewhat smaller variability than the low quality base layer.

We observe that the temporal base layer traffic is significantly more variable than the comparable single layer traffic. The $X^b_{\max}/\bar{X}^b$ is roughly 1.5 to 2 times the $X_{\max}/\bar{X}$. This large variability is due to the fact that the frames missing in the base layer are counted as zeros in the frame size analysis, i.e., the frame size analysis considers a scenario where each frame is transmitted during its frame period of 33 msec and nothing is transmitted during the periods of the skipped frames. (A scenario where the transmission of a base layer frame is distributed equally over the 100 msec between successive base layer frames is considered in Table 2 below.) Note, however, that the temporal base layer with a target bit rate of 64 kbps is highly variable. The extremely high peak–to–mean ratios are due to a few extremely large frames. The coefficient of variation for the rate-controlled base layer tends to decrease as the target bit rate increases. Overall, the coefficients of variation for the rate-controlled base layers are comparable to the coefficients of variation for the base layers without rate control.

In addition to X_n^b, $n = 0, \ldots, N-1$, we consider a smoothed base layer trace O_n^b, $n = 0, \ldots, N-1$, defined as follows. $O_{3k}^b = O_{3k+1}^b = O_{3k+2}^b = X_{3k}^b/3$ for $k = 0, \ldots, N/3-1$. (Note that analyzing O_n^b is equivalent to analyzing $X_n^{b(3)}$, the aggregated base layer trace with aggregation level $a = 3$.) The coefficient of variation $CoV_X^{b(3)}$, and the peak-to-mean ratio $X_{\max}^{b(3)}/\bar{X}^b$ are given in Table 2, along with the peak bit rate $X_{\max}^{b,(3)}/T$ of the smoothed trace.

Table 2: Overview of frame statistics of the smoothed base layer of temporal scalable encoded video

		Frame Size		Bit Rate
		CoV	Peak/Mean	Peak
Enc. M.	Video	$CoV_X^{b(3)}$	$X_{\max}^{b(3)}/\bar{X}^b$	$X_{\max}^{b(3)}/T$ [Mbps]
QCIF H.Q. No R.C.	*Citizen Kane*	0.670	5.703	1.351
	Die Hard I	0.447	3.359	1.041
	Jurassic Park I	0.532	4.064	1.541
	Silence of the Lambs	0.687	6.154	1.321
	Star Wars IV	0.538	5.325	1.400
	Star Wars V	0.489	3.355	1.231
	The Firm	0.586	4.372	1.299
	Terminator I	0.493	3.530	1.172
	Total Recall	0.468	3.742	1.202
	Aladdin	0.351	3.319	1.845
	Cinderella	0.428	5.055	2.095
	Baseball with Comm	0.375	3.227	1.352
	Snowboard with Comm	0.432	4.322	2.058
	Oprah w/o Comm	0.343	2.409	1.314
	Tonight Show w/o Comm	0.812	4.658	1.450
	Lecture-Gupta	0.326	2.679	1.333
	Lecture-Reisslein	0.440	4.029	2.142
QCIF H.–M.Q. No R.C.	*Jurassic Park I*	0.783	5.490	0.710
	Star Wars IV	0.837	9.551	0.799
	The Firm	0.933	6.846	0.639
	Tonight Show w/o Comm	1.123	7.491	0.756
QCIF M.Q. No R.C.	*Citizen Kane*	1.198	9.665	0.672
	Die Hard I	0.919	6.713	0.552
	Jurassic Park I	1.039	7.006	0.710
	Silence of the Lambs	1.233	12.597	0.676
	Star Wars IV	1.044	11.717	0.799
	Star Wars V	1.059	6.796	0.574
	The Firm	1.180	8.213	0.613
	Terminator I	0.887	5.600	0.541
	Total Recall	0.951	6.334	0.529
	Aladdin	0.848	5.493	0.748
	Cinderella	0.918	8.829	0.903
	Baseball with Comm	0.912	6.498	0.620
	Snowboard with Comm	0.884	6.859	0.857
	Oprah w/o Comm	0.957	5.043	0.609
	Tonight Show w/o Comm	1.443	8.832	0.703
	Lecture-Gupta	1.073	6.233	0.739
	Lecture-Reisslein	1.098	6.705	0.818
QCIF M.–L.Q. No R.C.	*Jurassic Park I*	0.812	6.351	0.300
	Star Wars IV	0.806	11.111	0.424
	The Firm	0.925	7.028	0.261
	Tonight Show w/o Comm	1.213	10.019	0.350
QCIF L.Q. No R.C.	*Citizen Kane*	0.847	7.156	0.219
	Die Hard I	0.640	5.467	0.214
	Jurassic Park I	0.716	5.926	0.232
	Silence of the Lambs	0.758	8.646	0.229
	Star Wars IV	0.707	10.104	0.342

Table 2: *continued*

		Frame Size		Bit Rate
		CoV	Peak/Mean	Peak
Enc. M.	Video	$CoV_X^{b(3)}$	$X_{\max}^{b(3)}/\bar{X}^b$	$X_{\max}^{b(3)}/T$ [Mbps]
	Star Wars V	0.750	5.970	0.216
	The Firm	0.805	6.191	0.198
	Terminator I	0.648	4.580	0.195
	Total Recall	0.656	4.796	0.185
	Aladdin	0.716	5.603	0.284
	Cinderella	0.707	9.019	0.368
	Baseball with Comm	0.660	4.930	0.201
	Snowboard with Comm	0.700	5.535	0.276
	Oprah w/o Comm	0.777	4.905	0.190
	Tonight Show w/o Comm	1.098	9.689	0.274
	Lecture-Gupta	1.098	6.759	0.278
	Lecture-Reisslein	1.067	8.289	0.338
QCIF R.C. 64 kbps	*Citizen Kane*	0.857	12.328	0.790
	Die Hard I	0.699	11.770	0.754
	Jurassic Park I	0.729	10.446	0.669
	Silence of the Lambs	0.704	8.930	0.572
	Star Wars IV	0.709	18.310	1.173
	Star Wars V	0.671	10.102	0.647
	The Firm	0.806	14.613	0.936
	Terminator I	0.666	19.685	1.261
	Total Recall	0.708	8.296	0.531
	Aladdin	0.642	17.616	1.128
	Cinderella	0.720	23.479	1.504
	Baseball with Comm	0.668	17.193	1.101
	Snowboard with Comm	0.626	17.158	1.099
	Oprah w/o Comm	0.777	13.097	0.839
	Tonight Show w/o Comm	0.825	8.501	0.544
	Lecture-Gupta	1.090	9.285	0.595
	Lecture-Reisslein	0.731	27.227	1.744
QCIF R.C. 128 kbps	*Citizen Kane*	0.642	4.007	0.513
	Die Hard I	0.527	3.781	0.484
	Jurassic Park I	0.591	3.807	0.487
	Silence of the Lambs	0.517	4.191	0.537
	Star Wars IV	0.518	3.699	0.474
	Star Wars V	0.500	3.533	0.452
	The Firm	0.619	4.357	0.558
	Terminator I	0.506	3.430	0.439
	Total Recall	0.534	4.296	0.550
	Aladdin	0.517	6.257	0.801
	Cinderella	0.533	5.640	0.722
	Baseball with Comm	0.486	3.585	0.459
	Snowboard with Comm	0.517	4.241	0.543
	Oprah w/o Comm	0.618	3.900	0.499
	Tonight Show w/o Comm	0.661	4.113	0.527
	Lecture-Gupta	0.754	3.268	0.419
	Lecture-Reisslein	0.613	3.544	0.454
QCIF R.C. 256 kbps	*Citizen Kane*	0.424	3.888	0.996
	Die Hard I	0.340	3.508	0.898
	Jurassic Park I	0.412	3.344	0.856
	Silence of the Lambs	0.328	3.539	0.906
	Star Wars IV	0.331	3.194	0.818
	Star Wars V	0.330	3.329	0.852
	The Firm	0.401	3.808	0.975
	Terminator I	0.328	3.296	0.844
	Total Recall	0.344	3.327	0.852
	Aladdin	0.331	2.835	0.726
	Cinderella	0.344	3.316	0.849
	Baseball with Comm	0.318	3.169	0.811
	Snowboard with Comm	0.344	3.468	0.888

Table 2: *continued*

Enc. M.	Video	Frame Size CoV $CoV_X^{b(3)}$	Frame Size Peak/Mean $X_{\max}^{b(3)}/\bar{X}^b$	Bit Rate Peak $X_{\max}^{b(3)}/T$ [Mbps]
	Oprah w/o Comm	0.418	3.391	0.868
	Tonight Show w/o Comm	0.453	3.229	0.827
	Lecture-Gupta	0.441	2.788	0.714
	Lecture-Reisslein	0.380	2.338	0.599

Aggregating three base layer frames (i.e., an I or P frame and two missing frames of size zero) or equivalently spreading the transmission of each base layer frame over three frame periods roughly reduces the standard deviation by a factor of three while leaving the mean unchanged. Thus, the coefficient of variation is reduced by roughly a factor of three. The peak bit rate and the peak-to-mean ratio of the $X_n^{b(3)}$ trace are exactly three times smaller compared to the unsmoothed X_n^b.

Comparing now the $X_n^{b(3)}$ traces with the corresponding single layer traces, we observe that the $X_n^{b(3)}$ trace is significantly less variable, with the $X_{\max}^{b(3)}/\bar{X}^b$ being typically one half to two thirds of the $X_{\max}/\bar{X}$. In other words the temporal base layer stream, consisting of I and P frames, is significantly less variable than the complete video stream. This indicates that the I and P frames are relatively less variable in size compared to the B frames. In other words, the B frames tend to be more variable in size compared to I and P frames. This is intuitive, as B frames can cover the entire range from being completely intra-coded (e.g., when the scene change occurs at that frame) to being completely inter-coded. In addition, the wide variety of motion vector types used in the predictive inter-coding contributes to the size variations. The variability of the B frames is studied in more detail in the section on the enhancement layer traffic. The observation of the base layer being less variable holds even stronger for the rate-controlled encodings with $X_{\max}^{b(3)}/\bar{X}^b$ typically being one third or less of the corresponding $X_{\max}/\bar{X}$. We also observe that the rate-controlled base layer has smaller coefficients of variation than the base layers without rate control.

Table 3 gives the mean *GoP* size ($\bar{Y}^b$), the coefficient of variation of the GoP sizes (CoV_Y^b), and the peak-to-mean ratio ($Y_{\max}^b/\bar{Y}^b$) of the GoP sizes, as well as the peak bit rate ($Y_{\max}^b/(GT)$) of the GoP trace. Note that at the GoP level there is no difference between the unsmoothed frame size trace X_n and the smoothed frame size trace O_n, i.e., both X_n, and O_n result in the same Y_m sequence.

Table 3: Overview of GoP statistics of the base layer of temporal scalable encoded video

Enc. M.	Video	GoP Size Mean $\bar{Y}[Kbyte]$	GoP Size CoV CoV_Y^b	GoP Size Peak/Mean $Y_{\max}^b/\bar{Y}^b$	Bit Rate Peak $Y_{\max}^b/(GT)$ [Mbps]
QCIF	*Citizen Kane*	11.848	0.479	4.508	1.068

Table 3: *continued*

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}[Kbyte]$	CoV_Y^b	$Y_{\max}^b/\bar{Y}^b$	$Y_{\max}^b/(GT)$ [Mbps]
H.Q.	*Die Hard I*	15.503	0.285	2.437	0.756
No R.C.	*Jurassic Park I*	18.961	0.404	3.509	1.331
	Silence of the Lambs	10.735	0.537	5.762	1.237
	Star Wars IV	13.148	0.377	4.879	1.283
	Star Wars V	18.352	0.391	2.527	0.927
	The Firm	14.853	0.427	3.654	1.085
	Terminator I	16.597	0.385	3.086	1.024
	Total Recall	16.058	0.322	2.582	0.829
	Aladdin	27.790	0.285	2.656	1.476
	Cinderella	20.721	0.331	3.945	1.635
	Baseball with Comm	20.953	0.281	2.637	1.105
	Snowboard with Comm	23.807	0.363	3.544	1.687
	Oprah w/o Comm	27.265	0.251	1.982	1.081
	Tonight Show w/o Comm	15.563	0.668	3.774	1.175
	Lecture-Gupta	24.885	0.230	2.061	1.026
	Lecture-Reisslein	26.585	0.393	2.011	1.069
QCIF	*Jurassic Park I*	6.465	0.486	4.596	0.594
H.–M.Q.	*Star Wars IV*	4.185	0.506	7.532	0.630
No R.C.	*The Firm*	4.671	0.580	4.920	0.460
	Tonight Show w/o Comm	5.046	0.708	5.002	0.505
QCIF	*Citizen Kane*	3.479	0.501	5.503	0.383
M.Q.	*Die Hard I*	4.110	0.375	3.207	0.264
No R.C.	*Jurassic Park I*	5.066	0.457	4.377	0.444
	Silence of the Lambs	2.683	0.664	8.617	0.462
	Star Wars IV	3.411	0.482	7.309	0.499
	Star Wars V	4.220	0.537	3.720	0.314
	The Firm	3.734	0.547	4.605	0.344
	Terminator I	4.830	0.443	3.659	0.353
	Total Recall	4.173	0.409	3.138	0.262
	Aladdin	6.805	0.458	3.853	0.524
	Cinderella	5.112	0.435	6.796	0.695
	Baseball with Comm	4.770	0.407	3.580	0.342
	Snowboard with Comm	6.247	0.458	4.570	0.571
	Oprah w/o Comm	6.037	0.307	2.990	0.361
	Tonight Show w/o Comm	3.978	0.686	4.785	0.381
	Lecture-Gupta	5.931	0.330	2.678	0.318
	Lecture-Reisslein	6.103	0.515	2.764	0.337
QCIF	*Jurassic Park I*	2.361	0.414	3.956	0.187
M.–L.Q.	*Star Wars IV*	1.909	0.438	6.776	0.259
No R.C.	*The Firm*	1.860	0.484	3.896	0.145
	Tonight Show w/o Comm	1.747	0.665	5.328	0.186
QCIF	*Citizen Kane*	1.527	0.403	4.124	0.126
L.Q.	*Die Hard I*	1.959	0.352	2.813	0.110
No R.C.	*Jurassic Park I*	1.960	0.367	3.274	0.128
	Silence of the Lambs	1.322	0.472	6.707	0.177
	Star Wars IV	1.694	0.391	5.778	0.196
	Star Wars V	1.811	0.443	3.392	0.123
	The Firm	1.595	0.425	3.321	0.106
	Terminator I	2.124	0.394	3.368	0.143
	Total Recall	1.933	0.373	2.639	0.102
	Aladdin	2.536	0.438	3.746	0.190
	Cinderella	2.039	0.397	7.139	0.291
	Baseball with Comm	2.041	0.383	2.950	0.120
	Snowboard with Comm	2.497	0.392	3.774	0.188
	Oprah w/o Comm	1.933	0.329	3.570	0.138
	Tonight Show w/o Comm	1.416	0.622	5.107	0.145
	Lecture-Gupta	2.057	0.298	2.959	0.122
	Lecture-Reisslein	2.036	0.466	3.131	0.127
QCIF	*Citizen Kane*	3.202	0.150	4.482	0.287

Table 3: *continued*

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}[Kbyte]$	CoV_Y^b	$Y^b_{\max}/\bar{Y}^b$	$Y^b_{\max}/(GT)$ [Mbps]
R.C.	*Die Hard I*	3.202	0.197	4.242	0.272
64 kbps	*Jurassic Park I*	3.202	0.179	5.134	0.329
	Silence of the Lambs	3.202	0.138	5.575	0.357
	Star Wars IV	3.202	0.201	9.733	0.623
	Star Wars V	3.202	0.223	7.253	0.465
	The Firm	3.202	0.176	4.003	0.256
	Terminator I	3.203	0.222	5.450	0.349
	Total Recall	3.202	0.190	3.714	0.238
	Aladdin	3.202	0.338	12.126	0.777
	Cinderella	3.202	0.248	6.410	0.411
	Baseball with Comm	3.202	0.214	4.680	0.300
	Snowboard with Comm	3.202	0.302	8.134	0.521
	Oprah w/o Comm	3.202	0.167	5.165	0.331
	Tonight Show w/o Comm	3.202	0.152	3.286	0.210
	Lecture-Gupta	3.202	0.143	5.781	0.370
	Lecture-Reisslein	3.202	0.183	10.074	0.645
QCIF	*Citizen Kane*	6.402	0.063	1.594	0.204
R.C.	*Die Hard I*	6.402	0.078	1.524	0.195
128 kbps	*Jurassic Park I*	6.402	0.069	1.417	0.181
	Silence of the Lambs	6.402	0.045	1.924	0.246
	Star Wars IV	6.402	0.074	1.503	0.192
	Star Wars V	6.402	0.076	1.462	0.187
	The Firm	6.402	0.072	1.444	0.185
	Terminator I	6.402	0.089	1.895	0.243
	Total Recall	6.402	0.082	1.450	0.186
	Aladdin	6.402	0.138	2.613	0.335
	Cinderella	6.402	0.108	2.256	0.289
	Baseball with Comm	6.402	0.080	1.635	0.209
	Snowboard with Comm	6.402	0.111	2.014	0.258
	Oprah w/o Comm	6.402	0.064	1.614	0.207
	Tonight Show w/o Comm	6.402	0.066	1.586	0.203
	Lecture-Gupta	6.402	0.051	1.488	0.191
	Lecture-Reisslein	6.402	0.042	1.438	0.184
QCIF	*Citizen Kane*	12.802	0.033	1.406	0.360
R.C.	*Die Hard I*	12.802	0.035	1.452	0.372
256 kbps	*Jurassic Park I*	12.802	0.033	1.409	0.361
	Silence of the Lambs	12.802	0.021	1.247	0.319
	Star Wars IV	12.802	0.033	1.385	0.355
	Star Wars V	12.802	0.037	1.404	0.359
	The Firm	12.802	0.033	1.273	0.326
	Terminator I	12.802	0.042	1.257	0.322
	Total Recall	12.802	0.036	1.231	0.315
	Aladdin	12.802	0.064	1.473	0.377
	Cinderella	12.802	0.049	1.722	0.441
	Baseball with Comm	12.802	0.034	1.334	0.342
	Snowboard with Comm	12.802	0.053	1.700	0.435
	Oprah w/o Comm	12.802	0.030	1.236	0.316
	Tonight Show w/o Comm	12.802	0.031	1.265	0.324
	Lecture-Gupta	12.802	0.021	1.190	0.305
	Lecture-Reisslein	12.802	0.019	1.240	0.317

For the encodings without rate control we observe again a peak in the traffic variability at the medium quality level. We also observe again that the temporal base layer GoP traffic is less variable than the corresponding single layer traffic. Also, the rate-controlled base layers are significantly less variable than the base layers without rate control. The coefficients of variation

CoV_X^b are good indicators of the general smoothness of the rate-controlled base layers at the GoP aggregation level. For the 256 kbps base layer the CoV_X^b are roughly an order of magnitude smaller than for the encodings without rate control. The CoV_X^b for the 128 kbps and 64 kbps are larger than for the 256 kbps base layer; however, the 128 kbps and 64 kbps CoV_X^b's are still significantly smaller than for the base layer without rate control. The 64 kbps base layers tend to have peak-to-mean GoP size ratios that are on the order of the ratios for the encodings without rate control. This is due to some extremely large GoPs, which are however rare.

The peak rates of the 128 kbps and 256 kbps base layers at the GoP aggregation level are quite close to the mean bit rate. The peak rates of the 128 kbps base layers are typically less than 200 kbps and the peak rates of the 256 kbps base layers are typically less than 300 kbps. This enables the transport of the base layer with rate control over reliable constant bit rate network "pipes" — provisioned, for instance, using the guaranteed service paradigm [1].

Note, that even these rate-controlled encodings at the GoP aggregation level require some amount of over-provisioning since the peak rates are larger than the mean bit rates. As illustrated in the following figures, (see in particular Figure 3) excursions above (and below) the mean bit rate are typically short-lived. Therefore, any of the common smoothing algorithms (e.g., [2], [3], [4], [5]) should be able to reduce the peak rates of the GoP streams to rates very close to the mean bit rate with a moderately-sized smoothing buffer. In addition, note that the TM5 rate control employed in our encodings is a basic rate control scheme which is standardized and widely used. More sophisticated and refined rate control schemes (see for example [6], [7], [8], [9], [10]) may further reduce the variability of the traffic (and also achieve a better rate-distortion performance).

Figure 1 gives the (unsmoothed) frame size X_n^b (in bytes) as a function of the frame number n. For the encodings with rate control we observe again the pronounced variability of the frame sizes. Note that the outlines of the upper borders of the shaded areas are strikingly similar to the corresponding outlines in Figure 1 of Part 2.

As we discuss in detail later in this part, the temporal base layer is approximately equivalent to extracting the I and P frames out of a single layer encoding. The plots in Figure 1 may serve as a visual "proof"; the large I and P frames, which span the upper borders of the shaded areas in the plots, are the same as in Figure 1 of Part 2.

The smaller B frames, which span the lower border of the shaded area in the plots of Figure 2 of Part 2 are replaced by zeros in the base layer size traces. Thus the shading extends to the x-axis in the corresponding regions of Figure 1. For the encodings with rate control we observe that the base layers appear to have fewer "spikes" of extremely large frames compared to the corresponding single layer encodings.

Figure 2 gives the smoothed frames size $X_n^{b(3)}$ (in bytes) as a function of the frame number n. These plots complement the statistics given in Table 2 for the smoothed base layer traces. While the smoothing over 3 frames has significantly reduced the variability by eliminating the "zeros" in the traces, there is still significant variability present, even for the rate-controlled sequences.

Figure 3 gives the GoP size Y_m^b (in bytes) as a function of the GoP number m. For encodings without rate control we observe the traffic variations that are typical for open-loop encodings. The GoP sizes of the encodings with rate control, on the other hand, are centered around the target GoP size, with only occasional excursions. Also, as already noted for Table 3, the GoP size traces of the base layer encodings have smaller outlines than the GoP sizes of the single layer encodings. Figure 3 underscores that the GoP size traffic of the temporal base layer is less variable.

In the following analysis we focus on the smoothed frame size trace O_n^b, $n = 0, \ldots, N-1$; for conciseness we analyze the equivalent trace $X_n^{b(3)}$, $n = 0, \ldots, N/3 - 1$.

Figure 4 gives the histograms of the frame sizes $X_n^{b(3)}$. Note that these histograms are quite similar to the histograms obtained by scaling the frame sizes in the single layer histograms in Figure 2 of Part 2 by a factor of three. The most significant difference is that the tails (probabilities for layer frame sizes) are amplified in the histograms here. This reflects the fact that the large I and P frames are in the base layer. Note that the encodings with rate control have two "humps", which are more pronounced here than for the single layer encodings.

Figure 5 gives the histograms of the GoP sizes Y_m. Most striking is that the GoP size histograms for the encodings with rate control are very narrow.

Figure 6 gives the autocorrelation coefficient $\rho^b_{X^{(3)}}(k)$ of the frame size sequence $X^{b(3)}_n$, $n = 0, \ldots, N/3 - 1$, as a function of the lag k (in frames). For the encodings without rate control we observe that the three small spikes between I frames which are present in the single layer, are absent in temporal base layer.

Figure 7 gives the autocorrelation coefficient $\rho^b_Y(k)$ of the GoP size sequence Y^b_m, $m = 0, \ldots, N/G - 1$, as a function of the lag k (in GoPs). We observe that the GoP autocorrelation functions for the base layer encodings without rate control are very similar to the autocorrelation functions of the single layer encodings. We also observe that the autocorrelation functions for the encodings with rate control drop off very quickly to zero and then either hover around zero with very small amplitudes (128 kbps and 256 kbps base layers) or somewhat larger amplitudes (64 kbps). The 64 kbps and 128 kbps base layer autocorrelation functions, in particular, are significantly closer to zero than the autocorrelation functions of the corresponding single layer encodings. This appears to indicate once more the better performance of the TM5 rate control for the base layers.

Table 4 gives the Hurst parameter obtained with the R/S heuristics and the periodogram for X^b_n, $n = 0, \ldots, N - 1$, as a function of the aggregation level a. Comparing Table 4 with the Table 3 of Part 2, we observe that the Hurst parameter estimates of the data generated by the two encoding types — single layer and temporal base layer — are almost the same for the different aggregation levels for encodings without rate control.

For the encodings with rate control, the Hurst parameter estimates are again below 0.5 for most videos and bit rates, making the estimates invalid. Only the 64 kbps *Alladin* and *Lecture–Reisslein* encodings have Hurst parameter estimates above 0.5, which, however, drop off to close to 0.5 for large aggregation levels. Thus, there is not a strong indication that these traces have long range dependence properties.

Table 4: Hurst parameters estimated from pox diagram of R/S and program as a function of the aggregation level a.

						Aggregation level a [frames]						
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
QCIF	*Citizen Kane*	0.921	0.926	0.917	0.904	0.891	0.898	0.892	0.887	0.881	0.863	0.831
H.Q.	*Citizen Kane*	1.148	1.168	1.168	1.052	0.969	0.912	0.898	0.918	0.939	1.024	0.853
No R.C.	*Die Hard I*	0.799	0.783	0.787	0.777	0.757	0.735	0.696	0.674	0.668	0.641	0.658
	Die Hard I	1.072	1.062	0.997	0.893	0.810	0.776	0.809	0.833	0.846	0.823	0.785
	Jurassic Park I	0.844	0.818	0.777	0.732	0.748	0.734	0.754	0.712	0.674	0.638	0.666
	Jurassic Park I	1.155	1.201	1.124	1.062	0.966	0.943	0.917	0.917	0.935	0.820	0.850
	Silence of the Lambs	0.910	0.891	0.883	0.909	0.922	0.904	0.892	0.815	0.820	0.837	0.759
	Silence of the Lambs	1.144	1.217	1.156	1.062	0.997	0.987	0.998	1.051	1.026	1.080	1.116
	Star Wars IV	0.857	0.851	0.836	0.821	0.809	0.823	0.818	0.840	0.841	0.857	0.857
	Star Wars IV	1.072	1.085	1.065	1.046	0.963	0.981	0.987	0.962	1.017	0.896	1.021
	Star Wars V	0.872	0.853	0.869	0.845	0.835	0.803	0.787	0.846	0.773	0.806	0.741
	Star Wars V	1.193	1.187	1.078	1.009	0.993	0.930	0.922	0.911	0.867	0.821	0.773
	The Firm	0.890	0.874	0.855	0.834	0.815	0.801	0.817	0.769	0.761	0.763	0.727
	The Firm	1.084	1.143	1.128	1.096	1.089	1.065	1.081	1.001	1.058	1.070	1.013
	Terminator I	0.899	0.901	0.894	0.888	0.866	0.864	0.885	0.866	0.823	0.787	0.850
	Terminator I	1.088	1.072	1.003	0.993	0.984	0.966	0.954	0.998	0.924	0.962	0.949
	Total Recall	0.888	0.885	0.868	0.870	0.865	0.850	0.853	0.864	0.850	0.849	0.874
	Total Recall	1.078	1.087	1.048	1.016	0.995	0.954	1.001	0.894	0.989	0.888	0.915
	Aladdin	0.873	0.861	0.865	0.858	0.871	0.872	0.836	0.808	0.804	0.759	0.753
	Aladdin	1.064	1.038	0.979	0.920	0.944	0.956	0.975	0.976	1.062	0.950	0.972

Table 4: *continued*

Enc. M.	Video	Aggregation level a [frames]										
		12	24	48	96	192	300	396	504	600	696	792
	Cinderella	0.848	0.839	0.845	0.850	0.844	0.890	0.856	0.838	0.863	0.811	0.874
	Cinderella	1.091	1.068	1.004	0.975	0.973	0.999	1.006	1.019	1.022	1.027	0.924
	Baseball with Comm	0.828	0.817	0.792	0.808	0.830	0.850	0.871	0.808	0.796	0.880	0.836
	Baseball with Comm	1.087	1.100	1.013	0.985	0.869	0.793	0.791	0.783	0.815	0.829	0.823
	Snowboard with Comm	0.776	0.757	0.726	0.698	0.669	0.664	0.656	0.697	0.705	0.664	0.722
	Snowboard with Comm	1.166	1.101	0.918	0.922	0.869	0.790	0.745	0.691	0.791	0.644	0.726
	Oprah w/o Comm	0.864	0.850	0.839	0.852	0.843	0.948	0.869	0.906	0.939	0.871	0.882
	Oprah w/o Comm	1.154	1.163	1.114	0.980	1.013	1.049	0.995	1.028	0.986	1.046	1.116
	Tonight Show w/o Comm	0.914	0.922	0.939	0.948	0.931	0.972	0.942	1.007	1.016	0.983	1.021
	Tonight Show w/o Comm	1.112	1.221	1.252	1.244	1.230	1.235	1.283	1.332	1.298	1.314	1.279
	Lecture-Gupta	1.012	0.996	0.971	0.959	0.923	0.952	0.914	0.946	0.950	0.918	0.917
	Lecture-Gupta	1.226	1.265	1.267	1.088	0.890	0.966	1.065	0.965	0.999	1.201	1.181
	Lecture-Reisslein	0.970	0.957	0.950	0.933	0.915	0.890	0.934	0.933	0.872	0.931	0.935
	Lecture-Reisslein	1.285	1.269	1.227	1.220	1.153	1.165	1.194	1.250	1.278	1.301	1.326
QCIF	*Jurassic Park I*	0.823	0.801	0.760	0.710	0.725	0.711	0.720	0.681	0.651	0.616	0.616
H.–M.Q.	*Jurassic Park I*	1.098	1.165	1.116	1.055	0.976	0.923	0.928	0.931	0.918	0.823	0.856
No R.C.	*Star Wars IV*	0.857	0.851	0.837	0.821	0.825	0.820	0.820	0.808	0.816	0.883	0.875
	Star Wars IV	1.009	1.037	1.055	1.058	1.005	0.977	0.998	0.964	1.022	0.909	0.952
	The Firm	0.903	0.896	0.869	0.851	0.834	0.831	0.846	0.789	0.788	0.779	0.764
	The Firm	1.019	1.074	1.112	1.090	1.104	1.096	1.108	1.079	1.083	1.086	1.066
	Tonight Show w/o Comm	0.887	0.904	0.911	0.943	0.925	0.970	0.928	0.998	1.031	1.023	1.065
	Tonight Show w/o Comm	1.067	1.162	1.189	1.206	1.180	1.187	1.259	1.290	1.290	1.329	1.264
QCIF	*Citizen Kane*	0.922	0.928	0.924	0.920	0.899	0.898	0.887	0.900	0.884	0.849	0.828
M.Q.	*Citizen Kane*	1.102	1.133	1.137	1.061	0.958	0.896	0.898	0.906	0.933	0.996	0.963
No R.C.	*Die Hard I*	0.809	0.788	0.790	0.770	0.756	0.741	0.698	0.696	0.685	0.642	0.686
	Die Hard I	1.021	1.046	0.991	0.904	0.834	0.799	0.870	0.851	0.831	0.785	0.764
	Jurassic Park I	0.824	0.799	0.760	0.713	0.728	0.714	0.720	0.687	0.657	0.623	0.619
	Jurassic Park I	1.091	1.155	1.109	1.054	0.985	0.924	0.926	0.915	0.921	0.818	0.854
	Silence of the Lambs	0.922	0.895	0.886	0.888	0.899	0.909	0.874	0.838	0.827	0.859	0.791
	Silence of the Lambs	1.064	1.154	1.128	1.067	1.007	0.986	1.009	1.049	1.049	1.124	1.129
	Star Wars IV	0.856	0.850	0.834	0.820	0.828	0.813	0.817	0.803	0.809	0.884	0.878
	Star Wars IV	1.007	1.035	1.055	1.057	1.011	0.980	0.994	0.961	1.023	0.912	0.950
	Star Wars V	0.879	0.858	0.865	0.856	0.829	0.813	0.799	0.869	0.812	0.851	0.782
	Star Wars V	1.116	1.130	1.042	0.986	0.970	0.934	0.931	0.922	0.955	0.848	0.869
	The Firm	0.907	0.895	0.870	0.855	0.837	0.838	0.848	0.793	0.794	0.784	0.770
	The Firm	1.014	1.068	1.105	1.095	1.103	1.096	1.105	1.089	1.078	1.073	1.071
	Terminator I	0.897	0.896	0.888	0.880	0.854	0.876	0.885	0.896	0.880	0.852	0.914
	Terminator I	1.035	1.058	0.999	0.998	0.982	0.962	0.969	0.961	0.949	0.997	0.948
	Total Recall	0.878	0.872	0.859	0.862	0.829	0.806	0.808	0.818	0.801	0.816	0.791
	Total Recall	1.016	1.041	1.038	1.009	1.014	0.976	1.002	0.880	0.949	0.877	0.902
	Aladdin	0.883	0.873	0.880	0.875	0.900	0.899	0.858	0.842	0.838	0.795	0.783
	Aladdin	1.039	1.026	0.974	0.933	0.976	0.956	0.994	0.970	1.037	0.898	0.982
	Cinderella	0.825	0.812	0.816	0.810	0.796	0.816	0.790	0.754	0.754	0.762	0.772
	Cinderella	1.049	1.046	0.996	0.961	0.957	0.960	0.938	0.959	0.969	0.936	0.813
	Baseball with Comm	0.801	0.790	0.758	0.758	0.791	0.814	0.845	0.805	0.790	0.885	0.861
	Baseball with Comm	1.045	1.076	1.033	0.988	0.827	0.752	0.721	0.733	0.710	0.789	0.736
	Snowboard with Comm	0.769	0.752	0.722	0.687	0.646	0.642	0.635	0.674	0.681	0.659	0.709
	Snowboard with Comm	1.107	1.061	0.915	0.903	0.845	0.768	0.725	0.667	0.763	0.650	0.708
	Oprah w/o Comm	0.815	0.792	0.764	0.751	0.722	0.771	0.697	0.701	0.743	0.692	0.685
	Oprah w/o Comm	1.075	1.089	1.057	0.960	0.950	0.939	0.894	0.906	0.900	0.897	0.948
	Tonight Show w/o Comm	0.893	0.904	0.916	0.955	0.928	0.980	0.935	1.015	1.045	1.035	1.075
	Tonight Show w/o Comm	1.052	1.151	1.184	1.209	1.180	1.185	1.263	1.281	1.285	1.328	1.265
	Lecture-Gupta	1.010	0.978	0.958	0.935	0.880	0.899	0.856	0.886	0.908	0.904	0.890
	Lecture-Gupta	1.164	1.222	1.240	1.141	0.979	1.016	1.029	0.906	0.930	1.221	1.081
	Lecture-Reisslein	0.972	0.967	0.948	0.933	0.927	0.901	0.948	0.950	0.887	0.957	0.954
	Lecture-Reisslein	1.180	1.211	1.226	1.220	1.174	1.143	1.184	1.218	1.234	1.247	1.313
QCIF	*Jurassic Park I*	0.818	0.795	0.770	0.719	0.718	0.708	0.695	0.713	0.658	0.613	0.619
M.–L.Q.	*Jurassic Park I*	1.025	1.103	1.056	1.011	0.978	0.914	0.941	0.878	0.903	0.813	0.859
No R.C.	*Star Wars IV*	0.827	0.830	0.799	0.789	0.812	0.797	0.813	0.802	0.811	0.853	0.887
	Star Wars IV	0.960	0.993	1.014	1.034	0.967	0.956	0.964	0.925	1.013	0.919	0.944
	The Firm	0.899	0.887	0.871	0.853	0.850	0.873	0.881	0.814	0.802	0.781	0.778
	The Firm	0.934	0.989	1.030	1.046	1.076	1.002	1.059	1.067	1.076	1.029	1.089
	Tonight Show w/o Comm	0.875	0.900	0.899	0.925	0.909	0.978	0.942	1.010	1.040	1.010	1.077
	Tonight Show w/o Comm	0.991	1.072	1.117	1.154	1.122	1.113	1.208	1.224	1.225	1.287	1.234
QCIF	*Citizen Kane*	0.903	0.900	0.900	0.891	0.890	0.913	0.898	0.913	0.880	0.859	0.826
L.Q.	*Citizen Kane*	1.014	1.041	1.072	1.007	0.909	0.843	0.848	0.828	0.896	0.902	0.911
No R.C.	*Die Hard I*	0.812	0.797	0.798	0.777	0.766	0.759	0.733	0.759	0.741	0.730	0.743
	Die Hard I	0.976	1.010	0.968	0.918	0.870	0.804	0.900	0.812	0.733	0.790	0.694
	Jurassic Park I	0.817	0.797	0.779	0.732	0.725	0.716	0.703	0.711	0.657	0.613	0.630
	Jurassic Park I	1.005	1.089	1.035	0.999	0.959	0.917	0.935	0.876	0.890	0.823	0.855
	Silence of the Lambs	0.913	0.904	0.909	0.909	0.927	0.910	0.922	0.864	0.861	0.872	0.864
	Silence of the Lambs	0.980	1.060	1.039	0.989	0.991	0.939	0.948	0.985	1.021	1.103	1.119
	Star Wars IV	0.818	0.820	0.788	0.778	0.799	0.787	0.805	0.796	0.801	0.840	0.869
	Star Wars IV	0.956	0.991	1.005	1.030	0.955	0.946	0.958	0.891	0.989	0.897	0.969
	Star Wars V	0.863	0.840	0.838	0.828	0.796	0.808	0.819	0.851	0.842	0.893	0.842
	Star Wars V	1.038	1.052	0.998	0.937	0.926	0.872	0.866	0.898	0.820	0.791	0.806
	The Firm	0.892	0.884	0.868	0.856	0.860	0.879	0.876	0.814	0.809	0.782	0.773
	The Firm	0.918	0.973	1.003	1.019	1.040	0.964	1.044	1.061	1.079	1.011	1.073
	Terminator I	0.913	0.911	0.893	0.878	0.860	0.880	0.888	0.880	0.889	0.875	0.914
	Terminator I	0.981	1.023	0.992	0.995	1.002	1.010	1.033	1.020	1.018	1.035	0.968
	Total Recall	0.869	0.846	0.830	0.819	0.796	0.787	0.792	0.787	0.809	0.796	0.764
	Total Recall	0.958	0.990	1.005	0.982	1.016	1.018	1.001	0.871	0.979	0.924	0.969
	Aladdin	0.880	0.866	0.867	0.878	0.908	0.910	0.866	0.856	0.846	0.816	0.801

Table 4: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	Aladdin	0.967	0.957	0.935	0.908	0.977	0.926	0.959	0.994	1.023	0.953	0.992
	Cinderella	0.806	0.800	0.802	0.788	0.768	0.761	0.731	0.715	0.686	0.726	0.721
	Cinderella	0.968	0.974	0.943	0.924	0.925	0.935	0.899	0.918	0.911	0.894	0.787
	Baseball with Comm	0.788	0.772	0.721	0.700	0.716	0.764	0.787	0.782	0.808	0.844	0.849
	Baseball with Comm	0.997	1.019	0.998	0.957	0.818	0.767	0.762	0.753	0.750	0.806	0.754
	Snowboard with Comm	0.764	0.736	0.701	0.656	0.619	0.606	0.607	0.627	0.671	0.629	0.673
	Snowboard with Comm	1.020	0.998	0.884	0.883	0.776	0.739	0.668	0.626	0.679	0.642	0.648
	Oprah w/o Comm	0.842	0.830	0.792	0.775	0.756	0.774	0.694	0.697	0.739	0.714	0.677
	Oprah w/o Comm	0.943	0.967	0.977	0.938	0.900	0.876	0.869	0.860	0.934	0.831	0.892
	Tonight Show w/o Comm	0.870	0.891	0.885	0.920	0.909	0.971	0.952	1.019	1.032	0.997	1.071
	Tonight Show w/o Comm	0.979	1.053	1.102	1.147	1.114	1.099	1.187	1.209	1.212	1.263	1.220
	Lecture-Gupta	0.986	0.945	0.930	0.907	0.846	0.874	0.798	0.848	0.868	0.844	0.810
	Lecture-Gupta	1.087	1.157	1.212	1.131	0.952	0.980	0.987	0.870	0.872	1.178	1.075
	Lecture-Reisslein	0.968	0.957	0.938	0.926	0.930	0.911	0.959	0.956	0.889	0.929	0.965
	Lecture-Reisslein	1.134	1.155	1.193	1.184	1.145	1.112	1.163	1.199	1.191	1.214	1.240
QCIF	*Citizen Kane*	0.383	0.396	0.432	0.385	0.364	0.339	0.430	0.404	0.358	0.476	0.433
R.C.	*Citizen Kane*	0.587	0.529	0.571	0.462	0.223	0.016	-0.186	-0.208	-0.193	-0.187	-0.167
64 kbps	*Die Hard I*	0.439	0.446	0.439	0.414	0.406	0.442	0.426	0.264	0.476	0.354	0.367
	Die Hard I	0.544	0.416	0.396	0.315	0.048	0.032	-0.122	-0.078	-0.160	-0.257	-0.175
	Jurassic Park I	0.576	0.599	0.598	0.586	0.530	0.506	0.442	0.417	0.377	0.373	0.394
	Jurassic Park I	0.650	0.616	0.712	0.817	0.799	0.622	0.598	0.340	0.354	-0.006	-0.016
	Silence of the Lambs	0.358	0.364	0.416	0.403	0.398	0.423	0.491	0.461	0.537	0.475	0.432
	Silence of the Lambs	0.608	0.747	0.891	0.933	0.840	0.454	0.275	0.169	0.320	0.031	-0.023
	Star Wars IV	0.349	0.384	0.393	0.389	0.353	0.431	0.429	0.421	0.444	0.471	0.401
	Star Wars IV	0.560	0.571	0.749	0.820	0.731	0.636	0.355	0.281	0.173	0.084	0.107
	Star Wars V	0.552	0.552	0.564	0.556	0.509	0.541	0.532	0.508	0.467	0.519	0.476
	Star Wars V	0.611	0.594	0.609	0.510	0.555	0.593	0.181	0.202	0.257	0.019	0.092
	The Firm	0.386	0.390	0.400	0.428	0.374	0.370	0.428	0.421	0.407	0.508	0.496
	The Firm	0.438	0.415	0.439	0.305	0.119	-0.115	-0.120	-0.190	0.038	-0.182	-0.025
	Terminator I	0.505	0.524	0.540	0.519	0.500	0.467	0.488	0.467	0.460	0.498	0.473
	Terminator I	0.640	0.527	0.521	0.522	0.450	0.325	0.227	0.105	0.039	-0.016	-0.006
	Total Recall	0.416	0.440	0.446	0.468	0.484	0.471	0.468	0.473	0.513	0.508	0.438
	Total Recall	0.479	0.353	0.353	0.252	0.177	0.011	-0.011	-0.079	-0.090	-0.092	-0.242
	Aladdin	0.629	0.626	0.597	0.609	0.616	0.648	0.525	0.589	0.552	0.467	0.534
	Aladdin	0.803	0.737	0.723	0.752	0.761	0.755	0.710	0.785	0.801	0.678	0.876
	Cinderella	0.449	0.441	0.436	0.438	0.430	0.401	0.417	0.424	0.388	0.444	0.343
	Cinderella	0.651	0.548	0.521	0.419	0.258	0.148	0.076	-0.042	0.003	-0.047	-0.072
	Baseball with Comm	0.418	0.395	0.369	0.353	0.343	0.359	0.397	0.395	0.436	0.336	0.363
	Baseball with Comm	0.604	0.445	0.307	0.240	0.085	-0.156	-0.039	-0.067	-0.184	-0.053	-0.141
	Snowboard with Comm	0.525	0.509	0.490	0.442	0.409	0.419	0.370	0.359	0.375	0.337	0.375
	Snowboard with Comm	0.783	0.651	0.606	0.558	0.417	0.281	0.150	-0.057	0.074	-0.026	0.023
	Oprah w/o Comm	0.473	0.500	0.479	0.445	0.457	0.407	0.413	0.386	0.377	0.485	0.484
	Oprah w/o Comm	0.595	0.520	0.552	0.358	0.136	-0.170	-0.173	-0.115	-0.053	-0.015	-0.294
	Tonight Show w/o Comm	0.489	0.512	0.503	0.449	0.411	0.382	0.396	0.448	0.317	0.452	0.438
	Tonight Show w/o Comm	0.629	0.552	0.577	0.423	0.160	-0.017	-0.089	-0.046	-0.112	-0.062	-0.144
	Lecture-Gupta	0.502	0.515	0.505	0.514	0.469	0.491	0.504	0.526	0.478	0.536	0.474
	Lecture-Gupta	0.864	0.812	0.804	0.899	0.871	0.850	0.859	1.166	0.822	0.505	0.394
	Lecture-Reisslein	0.661	0.674	0.635	0.622	0.551	0.588	0.562	0.585	0.633	0.503	0.547
	Lecture-Reisslein	0.944	0.855	0.883	0.965	0.917	1.010	1.011	0.908	1.017	0.879	1.007
QCIF	*Citizen Kane*	0.279	0.305	0.358	0.365	0.416	0.545	0.700	0.655	0.559	0.572	0.685
R.C.	*Citizen Kane*	0.014	-0.105	-0.167	-0.168	-0.116	-0.114	0.119	0.091	0.042	0.168	0.201
128 kbps	*Die Hard I*	0.248	0.230	0.282	0.320	0.342	0.423	0.365	0.362	0.495	0.344	0.672
	Die Hard I	-0.062	-0.164	-0.195	-0.111	-0.125	-0.086	0.052	0.039	0.128	0.074	0.160
	Jurassic Park I	0.219	0.234	0.262	0.351	0.400	0.375	0.660	0.505	0.652	0.449	0.681
	Jurassic Park I	-0.074	-0.178	-0.167	-0.156	-0.015	-0.053	0.081	0.075	0.110	0.090	0.025
	Silence of the Lambs	0.297	0.332	0.367	0.399	0.470	0.559	0.672	0.557	0.783	0.485	0.590
	Silence of the Lambs	0.138	0.174	0.102	-0.270	-0.104	-0.026	-0.108	-0.137	0.068	-0.024	-0.194
	Star Wars IV	0.221	0.232	0.261	0.269	0.347	0.408	0.420	0.678	0.609	0.667	0.476
	Star Wars IV	0.232	-0.024	-0.185	-0.139	-0.055	0.040	-0.045	0.080	0.014	0.080	0.172
	Star Wars V	0.248	0.280	0.295	0.320	0.330	0.356	0.542	0.467	0.466	0.601	0.505
	Star Wars V	0.239	0.159	0.146	-0.128	-0.077	0.180	0.029	-0.140	0.294	0.164	0.051
	The Firm	0.219	0.233	0.263	0.314	0.319	0.505	0.514	0.754	0.705	0.471	0.817
	The Firm	-0.081	-0.175	-0.189	-0.087	-0.132	0.053	0.004	0.144	0.248	-0.089	0.070
	Terminator I	0.263	0.275	0.319	0.304	0.350	0.373	0.395	0.423	0.412	0.555	0.344
	Terminator I	0.079	-0.065	-0.079	-0.175	-0.132	-0.084	-0.058	0.072	-0.142	0.101	-0.092
	Total Recall	0.201	0.228	0.258	0.271	0.331	0.348	0.394	0.432	0.484	0.430	0.605
	Total Recall	-0.091	-0.175	-0.189	-0.218	-0.111	-0.031	0.034	-0.026	0.018	0.084	0.119
	Aladdin	0.295	0.284	0.319	0.348	0.332	0.327	0.402	0.331	0.291	0.313	0.457
	Aladdin	0.281	0.161	0.194	-0.020	-0.216	-0.139	-0.183	-0.167	-0.100	0.183	-0.070
	Cinderella	0.371	0.347	0.369	0.308	0.367	0.358	0.489	0.464	0.552	0.453	0.509
	Cinderella	0.380	0.271	0.193	-0.240	-0.183	-0.141	-0.095	-0.194	0.001	-0.036	-0.132
	Baseball with Comm	0.235	0.270	0.299	0.301	0.328	0.401	0.413	0.623	0.617	0.497	0.538
	Baseball with Comm	0.002	-0.121	-0.171	-0.178	-0.168	-0.112	-0.114	-0.095	0.039	-0.016	0.193
	Snowboard with Comm	0.309	0.309	0.342	0.343	0.346	0.315	0.397	0.350	0.443	0.468	0.434
	Snowboard with Comm	0.198	0.000	-0.091	-0.147	-0.150	-0.086	-0.042	-0.131	-0.144	-0.294	-0.026
	Oprah w/o Comm	0.240	0.276	0.269	0.334	0.432	0.508	0.535	0.415	0.641	0.589	0.478
	Oprah w/o Comm	-0.020	-0.148	-0.205	-0.073	-0.024	0.033	-0.075	0.152	0.141	0.029	-0.087
	Tonight Show w/o Comm	0.283	0.311	0.332	0.318	0.397	0.359	0.518	0.551	0.531	0.502	0.540
	Tonight Show w/o Comm	0.016	-0.083	-0.153	-0.180	-0.183	-0.088	-0.006	0.025	-0.074	0.020	-0.017
	Lecture-Gupta	0.355	0.377	0.386	0.359	0.629	0.586	0.678	0.722	0.479	0.393	0.425
	Lecture-Gupta	-0.014	-0.065	-0.119	-0.152	-0.136	0.145	0.083	0.194	-0.019	0.153	-0.134
	Lecture-Reisslein	0.344	0.360	0.381	0.428	0.488	0.670	0.672	0.806	0.762	0.701	0.561
	Lecture-Reisslein	0.035	-0.134	-0.167	-0.112	-0.008	-0.042	0.066	0.191	0.031	0.103	-0.041
QCIF	*Citizen Kane*	0.347	0.333	0.345	0.343	0.400	0.400	0.706	0.778	0.617	1.109	0.789

Table 4: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
R.C.	*Citizen Kane*	-0.091	-0.158	-0.208	-0.206	-0.180	0.005	0.177	0.087	0.162	0.031	0.300
256 kbps	*Die Hard I*	0.308	0.269	0.290	0.359	0.343	0.340	0.530	0.694	0.792	0.752	0.693
	Die Hard I	-0.141	-0.199	-0.194	-0.130	-0.064	-0.028	0.100	0.168	0.094	0.136	0.334
	Jurassic Park I	0.288	0.281	0.313	0.342	0.427	0.399	0.596	0.691	0.639	0.556	1.090
	Jurassic Park I	-0.175	-0.181	-0.200	-0.187	-0.025	-0.000	0.107	0.116	0.158	-0.038	0.416
	Silence of the Lambs	0.299	0.275	0.306	0.293	0.388	0.503	0.655	0.831	0.515	0.633	0.690
	Silence of the Lambs	-0.179	-0.214	-0.178	-0.110	-0.059	0.096	0.108	0.139	0.245	0.296	0.418
	Star Wars IV	0.308	0.259	0.273	0.265	0.304	0.429	0.607	0.607	0.730	0.616	0.957
	Star Wars IV	-0.142	-0.160	-0.186	-0.110	-0.052	-0.011	0.117	0.098	0.175	0.135	0.258
	Star Wars V	0.302	0.299	0.320	0.301	0.325	0.423	0.620	0.480	0.635	0.856	0.747
	Star Wars V	0.174	0.136	0.126	-0.202	-0.166	0.264	-0.025	0.023	0.325	0.184	0.213
	The Firm	0.286	0.258	0.289	0.299	0.370	0.490	0.664	0.691	0.934	0.760	0.693
	The Firm	-0.156	-0.199	-0.202	-0.125	-0.076	0.041	0.086	0.126	0.315	0.297	0.194
	Terminator I	0.234	0.257	0.298	0.323	0.349	0.381	0.461	0.480	0.433	0.840	0.781
	Terminator I	-0.179	-0.190	-0.203	-0.178	-0.162	0.074	0.027	0.091	0.025	0.159	0.130
	Total Recall	0.240	0.254	0.267	0.247	0.325	0.420	0.667	0.387	0.495	0.653	0.932
	Total Recall	-0.186	-0.177	-0.211	-0.169	-0.100	-0.006	0.099	-0.147	0.007	0.237	0.297
	Aladdin	0.228	0.257	0.254	0.312	0.355	0.338	0.343	0.396	0.473	0.455	0.599
	Aladdin	-0.116	-0.206	-0.210	-0.201	-0.149	-0.088	-0.134	-0.160	-0.067	-0.057	0.004
	Cinderella	0.353	0.303	0.282	0.297	0.293	0.338	0.416	0.561	0.780	0.578	0.774
	Cinderella	0.185	-0.140	-0.234	-0.214	-0.118	-0.059	0.034	-0.000	0.131	0.154	0.115
	Baseball with Comm	0.265	0.302	0.304	0.345	0.378	0.419	0.508	0.563	0.564	0.525	0.753
	Baseball with Comm	-0.128	-0.191	-0.226	-0.139	-0.120	-0.021	0.084	0.059	0.077	0.043	0.136
	Snowboard with Comm	0.315	0.333	0.315	0.320	0.316	0.375	0.506	0.458	0.552	0.630	0.822
	Snowboard with Comm	-0.027	-0.144	-0.214	-0.176	-0.146	-0.146	-0.083	0.008	-0.042	-0.009	0.295
	Oprah w/o Comm	0.262	0.304	0.309	0.335	0.419	0.434	0.598	0.900	0.795	0.701	0.559
	Oprah w/o Comm	-0.148	-0.198	-0.176	-0.136	0.004	0.030	-0.040	0.191	0.110	0.185	0.073
	Tonight Show w/o Comm	0.265	0.280	0.340	0.343	0.384	0.532	0.586	0.696	0.987	0.694	0.743
	Tonight Show w/o Comm	-0.152	-0.165	-0.210	-0.193	-0.095	0.084	0.106	0.169	0.349	0.072	0.263
	Lecture-Gupta	0.363	0.373	0.314	0.261	0.454	0.835	0.708	0.933	0.836	0.805	0.753
	Lecture-Gupta	-0.159	-0.171	-0.157	-0.085	-0.067	0.176	0.115	0.326	0.461	0.328	0.363
	Lecture-Reisslein	0.354	0.367	0.306	0.251	0.318	0.579	0.851	0.950	0.876	0.596	0.949
	Lecture-Reisslein	-0.152	-0.206	-0.203	-0.126	0.093	-0.023	0.202	0.277	0.337	0.215	0.224

Table 5 gives the Hurst parameter estimated using the variance time plot as well as the scaling parameters $\underline{c}_f$ and α (also expressed as $H = (1+\alpha)/2$) estimated from the Logscale diagram.

Table 5: Hurst parameters estimated from variance time plot, scaling parameters estimated from Logscale diagram.

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
QCIF	*Citizen Kane*	0.866	0.005	0.983	0.991
H.Q.	*Die Hard I*	0.703	0.028	0.609	0.804
No R.C.	*Jurassic Park I*	0.685	0.002	1.092	1.046
	Silence of the Lambs	0.907	0.004	0.985	0.993
	Star Wars IV	0.805	0.002	1.034	1.017
	Star Wars V	0.729	0.004	0.980	0.990
	The Firm	0.824	0.001	1.277	1.138
	Terminator I	0.831	0.005	0.945	0.972
	Total Recall	0.771	0.001	1.150	1.075
	Aladdin	0.872	0.004	0.890	0.945
	Cinderella	0.878	0.008	0.808	0.904
	Baseball with Comm	0.799	0.001	1.164	1.082
	Snowboard with Comm	0.699	1.061	0.124	0.562
	Oprah w/o Comm	0.923	0.005	0.792	0.896
	Tonight Show w/o Comm	0.971	0.006	0.802	0.901
	Lecture-Gupta	0.860	0	1.045	1.022
	Lecture-Reisslein	0.953	0	1.480	1.240
QCIF	*Jurassic Park I*	0.646	0	1.443	1.221
H.–M.Q.	*Star Wars IV*	0.788	0.004	0.943	0.971
No R.C.	*The Firm*	0.842	0.001	1.276	1.138
	Tonight Show w/o Comm	0.962	0.016	0.677	0.838
QCIF	*Citizen Kane*	0.874	0.005	0.898	0.949
M.Q.	*Die Hard I*	0.713	0.012	0.758	0.879
No R.C.	*Jurassic Park I*	0.646	0	1.407	1.204
	Silence of the Lambs	0.901	0.001	0.771	0.885
	Star Wars IV	0.780	0.004	0.919	0.959
	Star Wars V	0.743	0.005	0.919	0.960
	The Firm	0.846	0	1.298	1.149
	Terminator I	0.831	0.005	0.917	0.958
	Total Recall	0.764	0.001	1.077	1.038
	Aladdin	0.875	0.006	0.907	0.953
	Cinderella	0.763	0.006	0.913	0.957
	Baseball with Comm	0.766	0.073	0.507	0.753
	Snowboard with Comm	0.612	0.931	0.129	0.564
	Oprah w/o Comm	0.812	0.005	0.789	0.894
	Tonight Show w/o Comm	0.964	0.010	0.671	0.836
	Lecture-Gupta	0.806	0	1.225	1.113
	Lecture-Reisslein	0.940	0	1.391	1.195
QCIF	*Jurassic Park I*	0.624	0.001	1.126	1.063
M.–L.Q.	*Star Wars IV*	0.764	0.121	0.394	0.697
No R.C.	*The Firm*	0.855	0.001	1.177	1.089
	Tonight Show w/o Comm	0.956	0.026	0.600	0.800
QCIF	*Citizen Kane*	0.869	0.007	0.835	0.918
L.Q.	*Die Hard I*	0.743	0.010	0.802	0.901
No R.C.	*Jurassic Park I*	0.632	0.001	1.174	1.087
	Silence of the Lambs	0.889	0.001	0.774	0.887
	Star Wars IV	0.756	0.121	0.390	0.695
	Star Wars V	0.742	0.004	0.994	0.997
	The Firm	0.856	0.001	1.117	1.058
	Terminator I	0.843	0.004	0.960	0.980
	Total Recall	0.742	0.002	1.025	1.013
	Aladdin	0.871	0.007	0.899	0.950

Table 5: *continued*

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
	Cinderella	0.723	0.009	0.837	0.919
	Baseball with Comm	0.701	0.060	0.554	0.777
	Snowboard with Comm	0.552	0.008	0.886	0.943
	Oprah w/o Comm	0.775	0.006	0.827	0.913
	Tonight Show w/o Comm	0.956	0	1.956	1.478
	Lecture-Gupta	0.775	0	1.175	1.088
	Lecture-Reisslein	0.943	0.001	1.076	1.038
QCIF	*Citizen Kane*	-0.453	7039127.108	-2.796	-0.898
R.C.	*Die Hard I*	-0.163	7005.122	-1.861	-0.431
64 kbps	*Jurassic Park I*	-0.181	21.882	-0.607	0.197
	Silence of the Lambs	-0.629	0.537	-1.442	-0.221
	Star Wars IV	-0.887	1344.59	-2.013	-0.507
	Star Wars V	-0.452	211.072	-1.186	-0.093
	The Firm	-0.459	368.630	-1.494	-0.247
	Terminator I	0.132	9968.815	-1.654	-0.327
	Total Recall	-0.053	2.456	-0.619	0.191
	Aladdin	0.760	0.720	-0.089	0.456
	Cinderella	-0.280	710.780	-1.394	-0.197
	Baseball with Comm	0.246	240.567	-1.302	-0.151
	Snowboard with Comm	0.210	0.235	0.154	0.577
	Oprah w/o Comm	0.103	2149.295	-1.694	-0.347
	Tonight Show w/o Comm	-0.080	20553.704	-1.920	-0.460
	Lecture-Gupta	-0.458	681341.111	-2.640	-0.820
	Lecture-Reisslein	0.771	0	1.039	1.019
QCIF	*Citizen Kane*	-0.109	3.029	-1.326	-0.163
R.C.	*Die Hard I*	-0.201	2.495	-1.275	-0.138
128 kbps	*Jurassic Park I*	-0.186	4.333	-1.359	-0.180
	Silence of the Lambs	0.053	3.394	-1.293	-0.147
	Star Wars IV	0.104	2.341	-1.295	-0.148
	Star Wars V	-0.179	3.340	-1.335	-0.168
	The Firm	0.145	2.734	-1.277	-0.139
	Terminator I	0.198	2.098	-1.249	-0.125
	Total Recall	-0.178	3.982	-1.332	-0.166
	Aladdin	-0.071	243.706	-1.745	-0.373
	Cinderella	-0.178	174.480	-2.177	-0.588
	Baseball with Comm	0.085	7.729	-1.456	-0.228
	Snowboard with Comm	-0.198	29.260	-1.544	-0.272
	Oprah w/o Comm	-0.183	1.067	-1.239	-0.120
	Tonight Show w/o Comm	0.294	8.470	-1.496	-0.248
	Lecture-Gupta	-0.322	0.088	-1.014	-0.007
	Lecture-Reisslein	0.176	0.031	-0.824	0.088
QCIF	*Citizen Kane*	-0.187	1.530	-1.299	-0.149
R.C.	*Die Hard I*	-0.190	0.792	-1.213	-0.107
256 kbps	*Jurassic Park I*	-0.114	1.232	-1.265	-0.133
	Silence of the Lambs	0.141	1.150	-1.313	-0.156
	Star Wars IV	0.186	1.142	-1.268	-0.134
	Star Wars V	-0.101	1.213	-1.255	-0.128
	The Firm	0.116	1.327	-1.269	-0.135
	Terminator I	0.293	0.428	-1.120	-0.060
	Total Recall	-0.092	2.376	-1.376	-0.188
	Aladdin	0.079	0.462	-1.228	-0.114
	Cinderella	-0.129	16.997	-1.699	-0.349
	Baseball with Comm	0.051	1.590	-1.323	-0.161
	Snowboard with Comm	-0.030	1.379	-1.202	-0.101
	Oprah w/o Comm	-0.163	0.565	-1.234	-0.117
	Tonight Show w/o Comm	0.181	3.384	-1.469	-0.235
	Lecture-Gupta	-0.091	0.077	-1.078	-0.039
	Lecture-Reisslein	0.007	0.019	-0.948	0.026

Table 6 gives the scaling parameters α_q for the orders $q = 0.5$, 1, 1.5, 2, 2.5, 3, 3.5, and 4.

Table 6: Scaling parameters estimated from multi scale diagram.

		Multi scale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
QCIF	*Citizen Kane*	0.558	1.060	1.517	1.939	2.336	2.714	3.079	3.432
H.Q.	*Die Hard I*	0.406	0.811	1.202	1.577	1.938	2.288	2.628	2.959
No R.C.	*Jurassic Park I*	0.538	1.064	1.580	2.098	2.620	3.143	3.660	4.170
	Silence of the Lambs	0.533	1.029	1.508	1.978	2.443	2.904	3.361	3.815
	Star Wars IV	0.541	1.077	1.598	2.103	2.584	3.038	3.409	3.815
	Star Wars V	0.504	1.002	1.486	1.957	2.417	2.865	3.303	3.731
	The Firm	0.576	1.149	1.711	2.260	2.787	3.296	3.790	4.272
	Terminator I	0.514	1.001	1.473	1.933	2.384	2.828	3.268	3.703
	Total Recall	0.560	1.101	1.629	2.152	2.675	3.199	3.722	4.244
	Aladdin	0.493	0.972	1.434	1.881	2.315	2.739	3.155	3.565
	Cinderella	0.474	0.938	1.382	1.804	2.203	2.583	2.945	3.294
	Baseball with Comm	0.573	1.124	1.651	2.160	2.663	3.146	3.621	4.089
	Snowboard with Comm	0.240	0.512	0.800	1.090	1.374	1.645	1.901	2.140
	Oprah w/o Comm	0.464	0.902	1.329	1.751	2.168	2.577	2.976	3.364
	Tonight Show w/o Comm	0.557	1.085	1.595	2.086	2.556	3.007	3.444	3.868
	Lecture-Gupta	0.679	1.190	1.604	1.973	2.320	2.656	2.986	3.314
	Lecture-Reisslein	0.712	1.388	1.993	2.532	3.030	3.509	3.978	4.441
QCIF	*Jurassic Park I*	0.613	1.219	1.826	2.437	3.049	3.644	4.223	4.803
H.–M.Q.	*Star Wars IV*	0.510	1.004	1.480	1.930	2.350	2.746	3.123	3.493
No R.C.	*The Firm*	0.570	1.139	1.700	2.244	2.765	3.262	3.741	4.213
	Tonight Show w/o Comm	0.547	1.071	1.564	2.024	2.456	2.866	3.261	3.648
QCIF	*Citizen Kane*	0.539	1.027	1.468	1.870	2.245	2.601	2.944	3.276
M.Q.	*Die Hard I*	0.450	0.891	1.320	1.737	2.143	2.535	2.916	3.286
No R.C.	*Jurassic Park I*	0.598	1.200	1.806	2.419	3.033	3.630	4.211	4.784
	Silence of the Lambs	0.597	1.115	1.515	1.803	1.991	2.099	2.146	2.149
	Star Wars IV	0.502	0.993	1.468	1.919	2.342	2.740	3.119	3.486
	Star Wars V	0.493	0.975	1.443	1.897	2.336	2.761	3.173	3.573
	The Firm	0.567	1.142	1.721	2.302	2.880	3.460	4.031	4.594
	Terminator I	0.513	1.001	1.470	1.921	2.358	2.784	3.200	3.610
	Total Recall	0.536	1.068	1.593	2.113	2.627	3.137	3.651	4.158
	Aladdin	0.502	0.987	1.454	1.905	2.341	2.762	3.172	3.574
	Cinderella	0.504	1.000	1.487	1.956	2.395	2.803	3.188	3.561
	Baseball with Comm	0.377	0.747	1.104	1.453	1.797	2.139	2.481	2.823
	Snowboard with Comm	0.254	0.527	0.807	1.079	1.332	1.561	1.767	1.951
	Oprah w/o Comm	0.485	0.928	1.350	1.755	2.147	2.526	2.892	3.245
	Tonight Show w/o Comm	0.549	1.069	1.554	2.003	2.421	2.818	3.201	3.576
	Lecture-Gupta	0.708	1.260	1.740	2.202	2.662	3.124	3.585	4.045
	Lecture-Reisslein	0.690	1.307	1.850	2.335	2.801	3.219	3.617	4.004
QCIF	*Jurassic Park I*	0.510	1.024	1.557	2.114	2.679	3.241	3.793	4.331
M.–L.Q.	*Star Wars IV*	0.352	0.714	1.061	1.388	1.695	1.982	2.249	2.498
No R.C.	*The Firm*	0.537	1.080	1.627	2.180	2.737	3.294	3.854	4.406
	Tonight Show w/o Comm	0.534	1.032	1.486	1.902	2.287	2.649	2.996	3.332
QCIF	*Citizen Kane*	0.506	0.972	1.404	1.813	2.206	2.590	2.969	3.345
L.Q.	*Die Hard I*	0.467	0.919	1.360	1.794	2.225	2.656	3.088	3.519
No R.C.	*Jurassic Park I*	0.549	1.080	1.610	2.147	2.689	3.228	3.760	4.283
	Silence of the Lambs	0.713	1.123	1.393	1.578	1.708	1.800	1.865	1.912
	Star Wars IV	0.375	0.728	1.067	1.391	1.696	1.983	2.250	2.500
	Star Wars V	0.523	1.028	1.520	2.000	2.465	2.914	3.358	3.781
	The Firm	0.525	1.049	1.578	2.113	2.655	3.197	3.735	4.276
	Terminator I	0.508	1.008	1.499	1.977	2.443	2.898	3.343	3.781
	Total Recall	0.524	1.035	1.537	2.031	2.513	2.986	3.451	3.907
	Aladdin	0.491	0.971	1.440	1.897	2.344	2.782	3.211	3.631
	Cinderella	0.494	0.967	1.414	1.827	2.199	2.536	2.896	3.217
	Baseball with Comm	0.373	0.746	1.125	1.509	1.895	2.283	2.668	3.050
	Snowboard with Comm	0.487	0.961	1.419	1.867	2.308	2.743	3.175	3.605
	Oprah w/o Comm	0.497	0.955	1.388	1.803	2.202	2.588	2.961	3.325

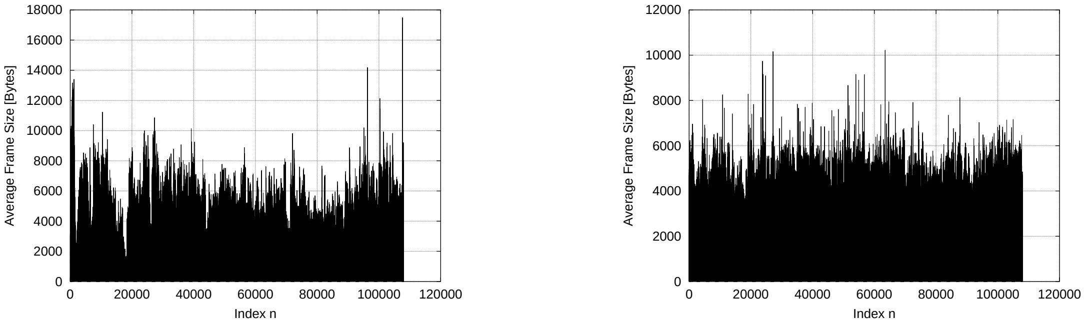
Table 6: *continued*

		Multi scale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
	Tonight Show w/o Comm	0.821	1.557	2.288	2.996	3.671	4.312	4.924	5.512
	Lecture-Gupta	0.670	1.215	1.692	2.146	2.596	3.049	3.502	3.955
	Lecture-Reisslein	0.624	1.178	1.666	2.103	2.509	2.898	3.279	3.656
QCIF	*Citizen Kane*	-0.210	-0.648	-1.221	-1.812	-2.409	-3.018	-3.638	-4.268
R.C.	*Die Hard I*	-0.044	-0.208	-0.512	-0.896	-1.319	-1.762	-2.218	-2.682
64 kbps	*Jurassic Park I*	0.413	0.501	0.460	0.406	0.352	0.296	0.237	0.174
	Silence of the Lambs	-0.539	-0.968	-1.398	-1.855	-2.359	-2.914	-3.515	-4.148
	Star Wars IV	-0.124	-0.387	-0.804	-1.377	-2.051	-2.770	-3.505	-4.242
	Star Wars V	0.394	0.175	-0.304	-0.844	-1.396	-1.946	-2.494	-3.039
	The Firm	0.013	-0.027	-0.211	-0.501	-0.843	-1.208	-1.583	-1.964
	Terminator I	0.068	-0.072	-0.357	-0.704	-1.077	-1.462	-1.852	-2.245
	Total Recall	0.207	0.437	0.663	0.844	0.947	1.023	1.116	1.241
	Aladdin	0.238	0.497	0.775	1.075	1.381	1.702	2.003	2.302
	Cinderella	0.107	0.011	-0.204	-0.447	-0.688	-0.922	-1.149	-1.370
	Baseball with Comm	-0.104	-0.203	-0.274	-0.323	-0.362	-0.396	-0.430	-0.466
	Snowboard with Comm	0.248	0.548	0.860	1.163	1.450	1.722	1.979	2.226
	Oprah w/o Comm	-0.008	-0.169	-0.425	-0.704	-0.984	-1.262	-1.538	-1.815
	Tonight Show w/o Comm	0.033	-0.206	-0.637	-1.137	-1.662	-2.196	-2.735	-3.279
	Lecture-Gupta	-0.067	-0.526	-1.263	-2.034	-2.783	-3.519	-4.250	-4.982
	Lecture-Reisslein	0.487	1.122	1.683	2.180	2.641	3.081	3.507	3.925
QCIF	*Citizen Kane*	-0.059	-0.120	-0.185	-0.260	-0.352	-0.464	-0.596	-0.748
R.C.	*Die Hard I*	-0.068	-0.143	-0.221	-0.307	-0.401	-0.504	-0.617	-0.740
128 kbps	*Jurassic Park I*	-0.055	-0.115	-0.183	-0.265	-0.362	-0.472	-0.599	-0.739
	Silence of the Lambs	-0.085	-0.142	-0.162	-0.135	-0.059	0.027	0.121	0.190
	Star Wars IV	-0.097	-0.167	-0.223	-0.276	-0.329	-0.386	-0.445	-0.507
	Star Wars V	-0.034	-0.103	-0.194	-0.301	-0.420	-0.549	-0.685	-0.829
	The Firm	-0.044	-0.095	-0.157	-0.233	-0.323	-0.429	-0.549	-0.680
	Terminator I	-0.043	-0.103	-0.183	-0.299	-0.451	-0.638	-0.852	-1.083
	Total Recall	-0.058	-0.124	-0.202	-0.291	-0.391	-0.499	-0.616	-0.738
	Aladdin	-0.072	-0.201	-0.434	-0.761	-1.128	-1.501	-1.874	-2.244
	Cinderella	-0.218	-0.518	-0.861	-1.234	-1.642	-2.084	-2.553	-3.041
	Baseball with Comm	-0.094	-0.188	-0.287	-0.392	-0.501	-0.614	-0.741	-0.873
	Snowboard with Comm	-0.096	-0.194	-0.310	-0.446	-0.597	-0.758	-0.928	-1.105
	Oprah w/o Comm	-0.063	-0.093	-0.103	-0.106	-0.113	-0.128	-0.155	-0.195
	Tonight Show w/o Comm	-0.084	-0.150	-0.217	-0.290	-0.373	-0.467	-0.572	-0.688
	Lecture-Gupta	-0.006	0.025	0.055	0.068	0.058	0.025	-0.027	-0.095
	Lecture-Reisslein	0.063	0.138	0.205	0.258	0.296	0.320	0.330	0.329
QCIF	*Citizen Kane*	-0.047	-0.087	-0.123	-0.159	-0.200	-0.248	-0.304	-0.370
R.C.	*Die Hard I*	-0.063	-0.116	-0.170	-0.229	-0.294	-0.363	-0.436	-0.513
256 kbps	*Jurassic Park I*	-0.057	-0.109	-0.168	-0.236	-0.318	-0.407	-0.504	-0.608
	Silence of the Lambs	-0.059	-0.115	-0.169	-0.229	-0.296	-0.376	-0.466	-0.577
	Star Wars IV	-0.057	-0.116	-0.171	-0.224	-0.280	-0.344	-0.421	-0.512
	Star Wars V	-0.030	-0.070	-0.115	-0.164	-0.215	-0.268	-0.322	-0.378
	The Firm	-0.046	-0.087	-0.124	-0.161	-0.200	-0.244	-0.289	-0.338
	Terminator I	-0.012	-0.044	-0.084	-0.129	-0.178	-0.231	-0.287	-0.347
	Total Recall	-0.048	-0.124	-0.214	-0.315	-0.425	-0.544	-0.669	-0.801
	Aladdin	-0.032	-0.078	-0.131	-0.188	-0.248	-0.309	-0.372	-0.434
	Cinderella	-0.157	-0.296	-0.422	-0.540	-0.659	-0.777	-0.911	-1.062
	Baseball with Comm	-0.047	-0.107	-0.167	-0.232	-0.296	-0.359	-0.419	-0.482
	Snowboard with Comm	-0.022	-0.056	-0.106	-0.176	-0.266	-0.368	-0.497	-0.634
	Oprah w/o Comm	-0.050	-0.072	-0.072	-0.064	-0.059	-0.062	-0.075	-0.100
	Tonight Show w/o Comm	-0.106	-0.178	-0.231	-0.275	-0.315	-0.354	-0.394	-0.436
	Lecture-Gupta	-0.009	0.020	0.056	0.078	0.076	0.047	-0.004	-0.071
	Lecture-Reisslein	0.102	0.166	0.188	0.151	0.046	-0.123	-0.343	-0.597

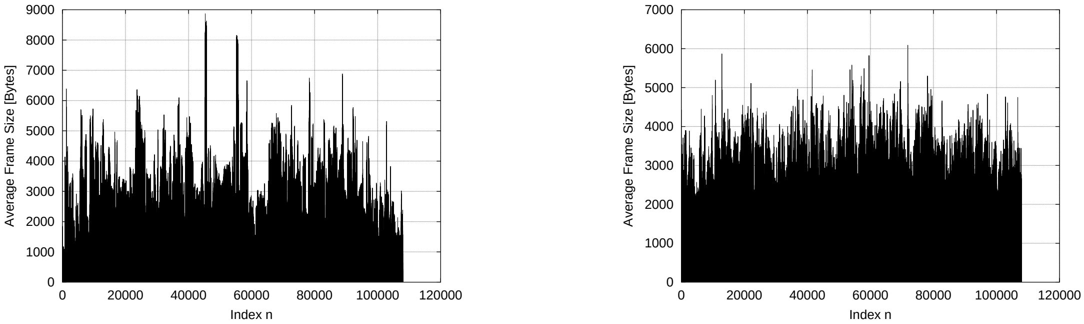
Figures 8, 9, and 10 give the variance-time plots, the pox plots of R/S (for $a = 12$), and the periodograms (for $a = 12$). Figure 11 gives the logscale diagrams. Figures 12 and 13 give the multiscale diagrams and the linear multiscale diagrams. From Table 5 we observe that in most cases the logscale H estimate closely matches that of the single layer. However, some video sequences show a considerable difference in the H estimate than what was observed for the single layer encodings. For example, the high quality *Star Wars IV* encoding has an H estimate of 0.8 for the single layer, whereas the temporal base layer has 1.017. The logscale diagram H estimates are negative for the 64 kbps target bit rate base layer encodings because of the effectiveness of rate control at 64 kbps. In single layer encodings where we do not find rate control at 64 kbps to be effective, we observe large values of H (typically larger than 0.5) estimate using logscale technique.

The Hurst parameter estimates obtained from the variance test analysis have roughly the same value for both the single layer and temporal base layer encodings. As was observed earlier, the variance test analysis gives the lowest estimate of the Hurst parameter compared to the other methods.

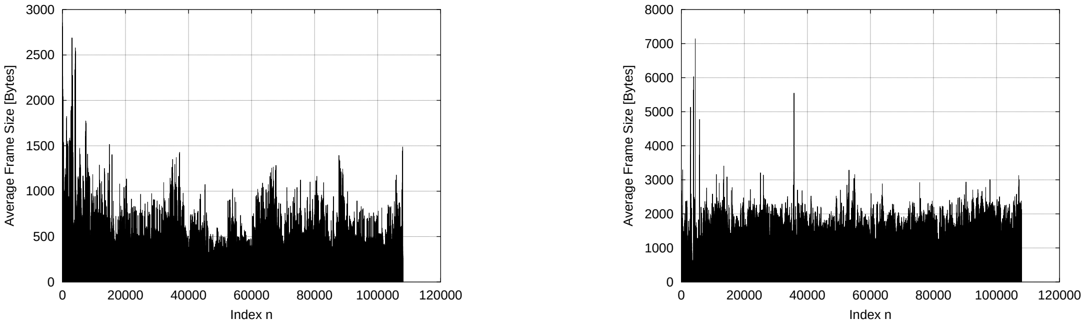
From Figure 11 we observe that the logscale plots for temporal base layer encodings without rate control exhibit the same properties as were observed in the logscale plots for the single layer encodings in Figure 9 of Part 2. As was observed for the single layer encodings, we again observe a “knee” around scale $j = 4$ or $j = 5$. Since we have only I and P frames in the temporal base layer encodings, the similarities of the logscale plots here with the plots in Figure 9 of Part 2 appear to indicate that the scaling properties of the I and P frame sequence are the same as for the full I, P and B frame sequence.



a) *Star Wars IV* with high quality   d) *Star Wars IV* with 256 kbps target bit rate



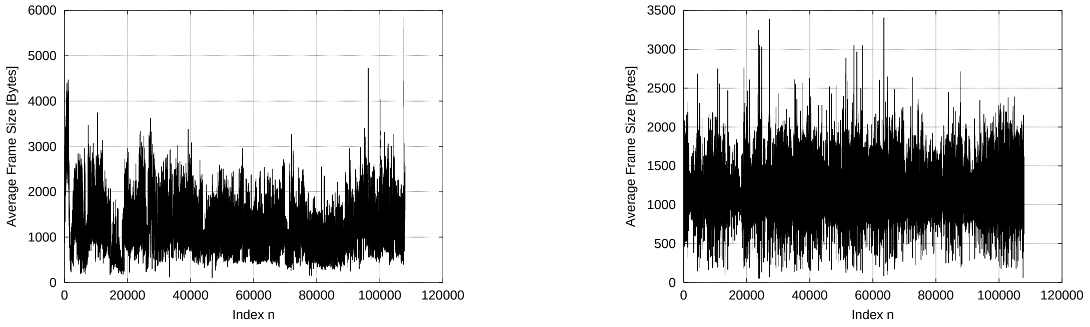
b) *Jurassic Park I* with medium quality   e) *Jurassic Park I* with 128 kbps target bit rate



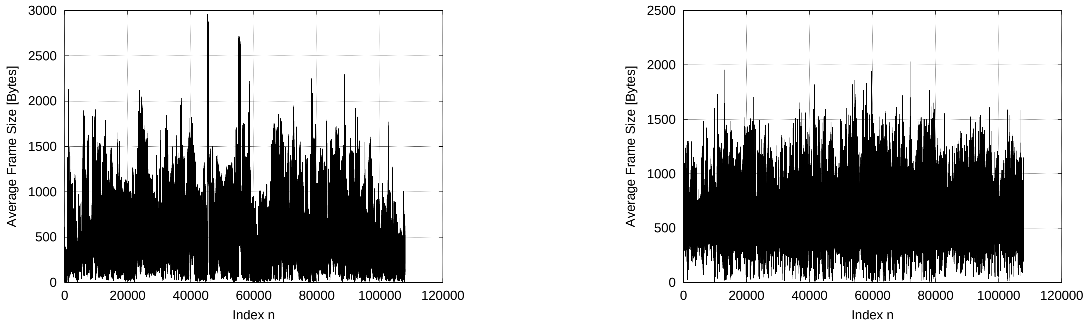
c) *Silence of the Lambs* with low quality   f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control   Encoding with rate control

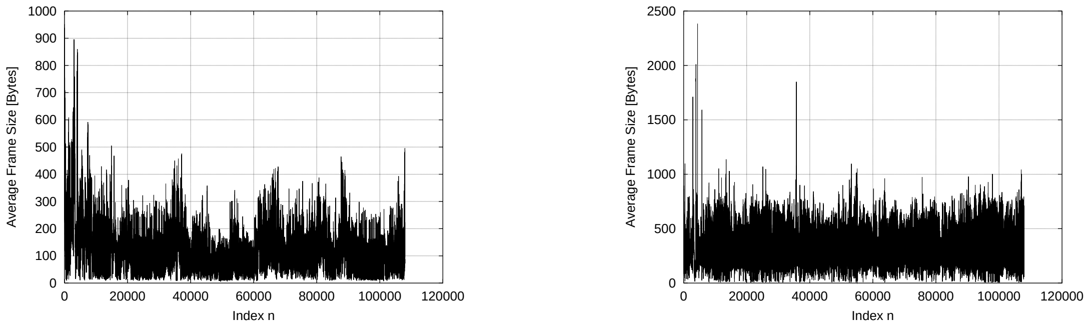
Figure 1: Base layer frame size X_n^b as a function of the frame index n for temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



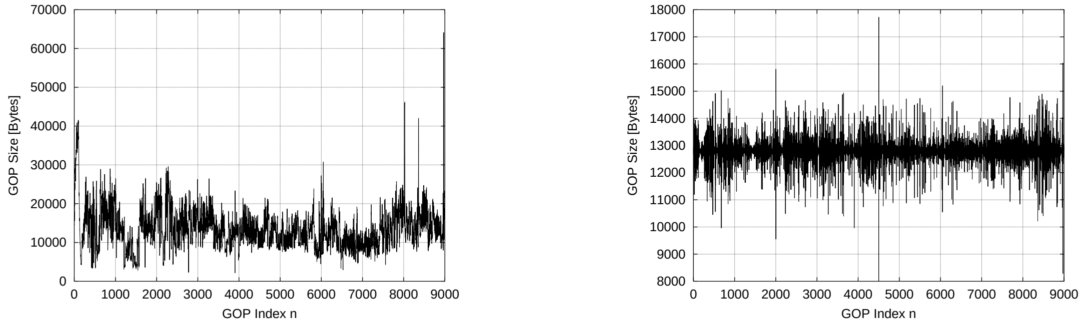
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



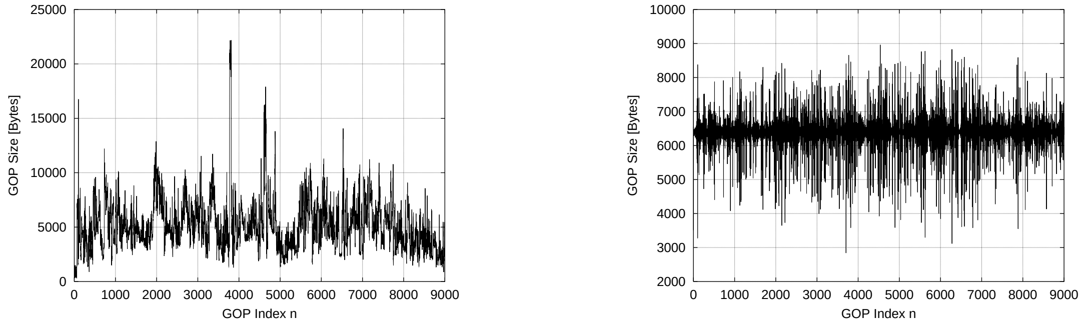
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

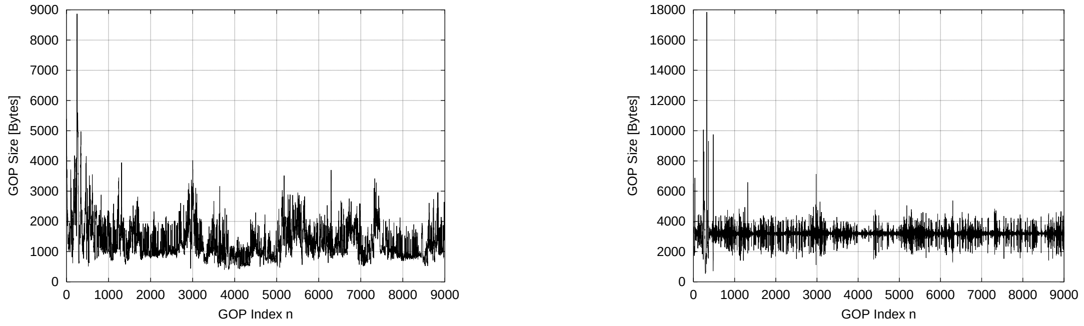
Figure 2: Smoothed base layer frame size X_n^b as a function of the frame index n for temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



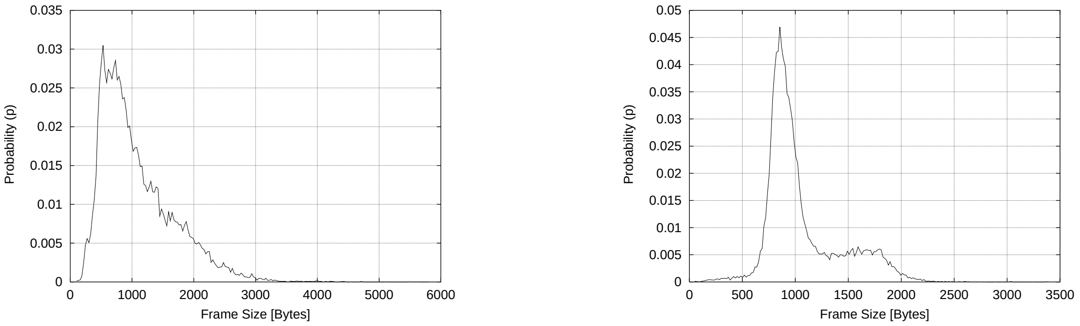
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

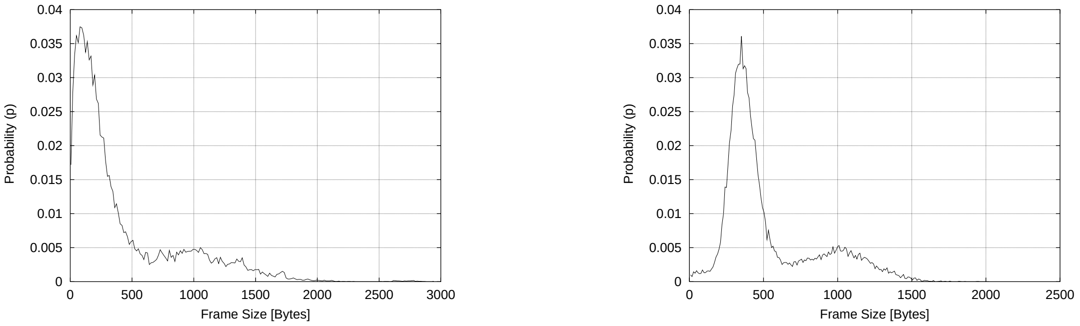
Encoding without rate control Encoding with rate control

Figure 3: GoP size Y_m^b as a function of the index m for temporal scalable QCIF video.



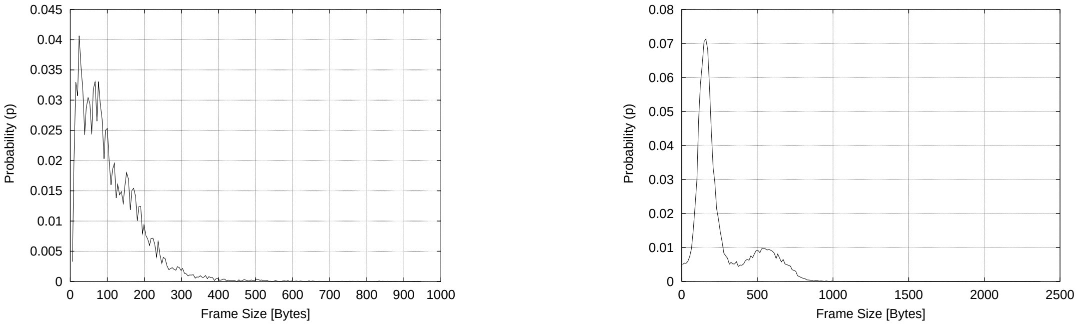
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



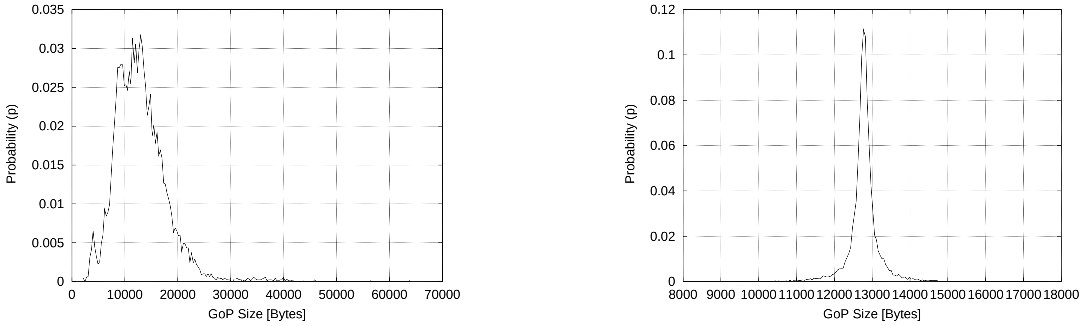
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

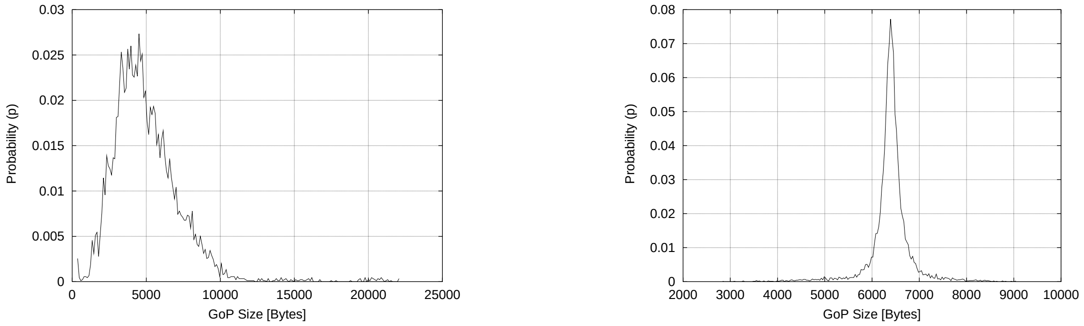
Encoding without rate control

Encoding with rate control

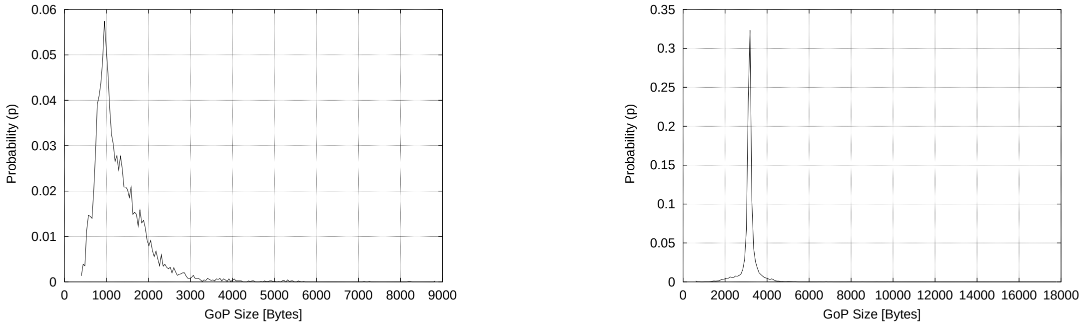
Figure 4: Frame size histograms for the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



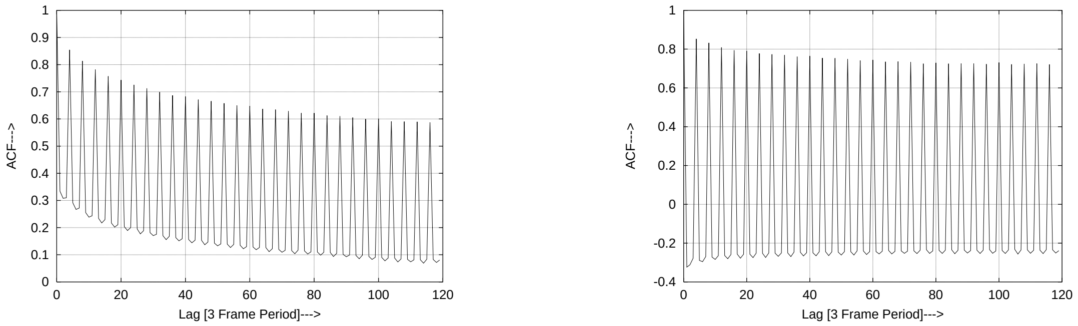
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



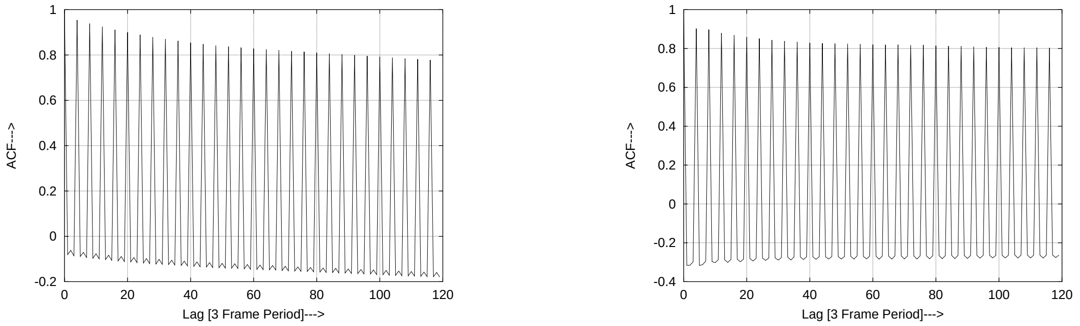
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

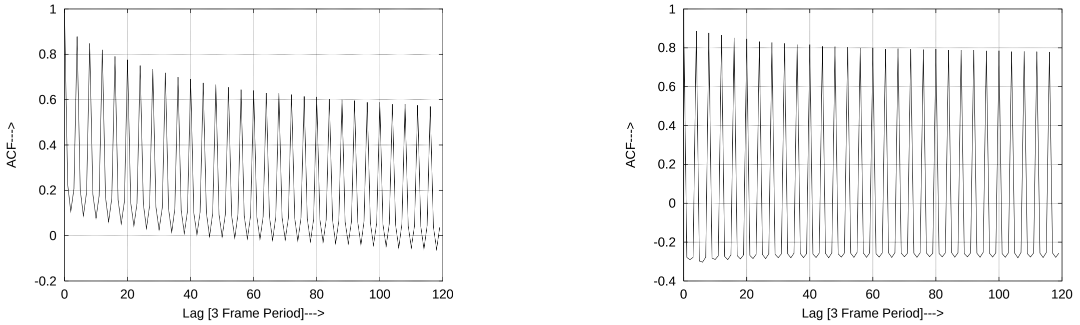
Figure 5: GoP size histograms for the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality   d) *Star Wars IV* with 256 kbps target bit rate



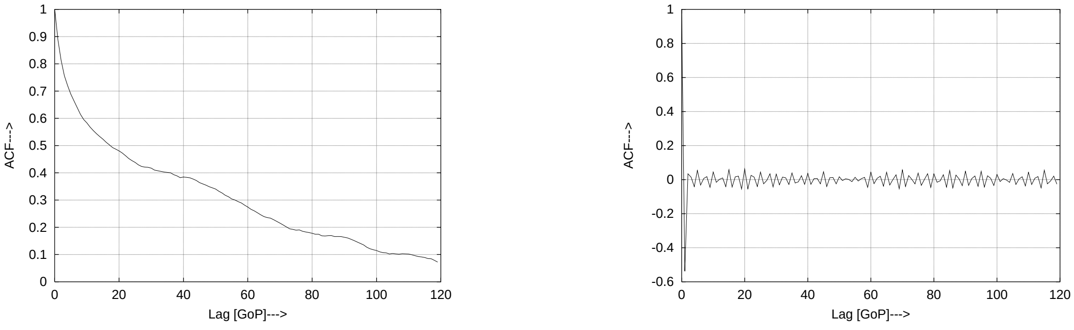
b) *Jurassic Park I* with medium quality   e) *Jurassic Park I* with 128 kbps target bit rate



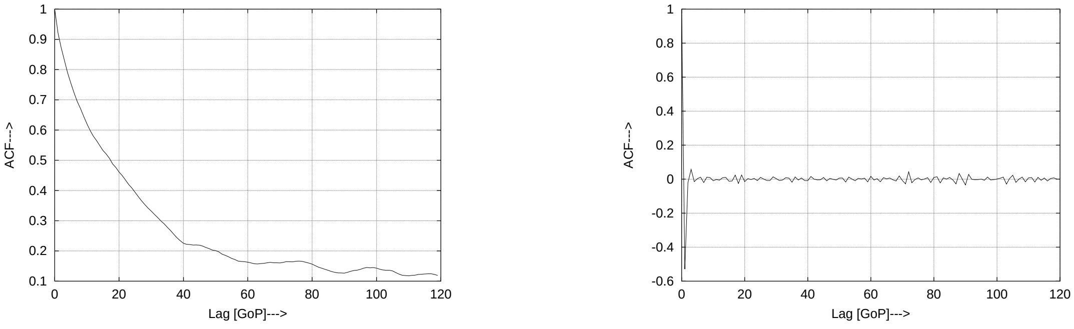
c) *Silence of the Lambs* with low quality   f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control   Encoding with rate control

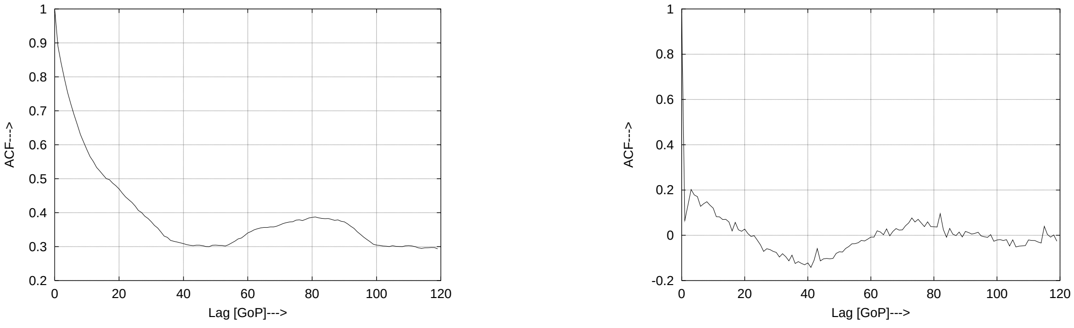
Figure 6: Frame size autocorrelations for the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



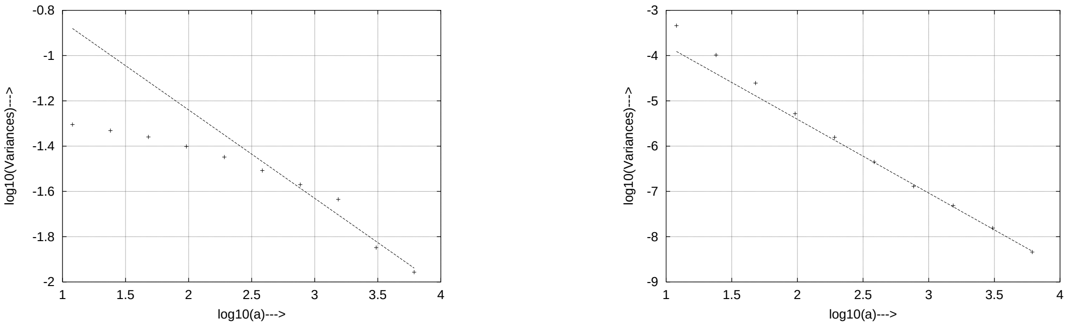
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



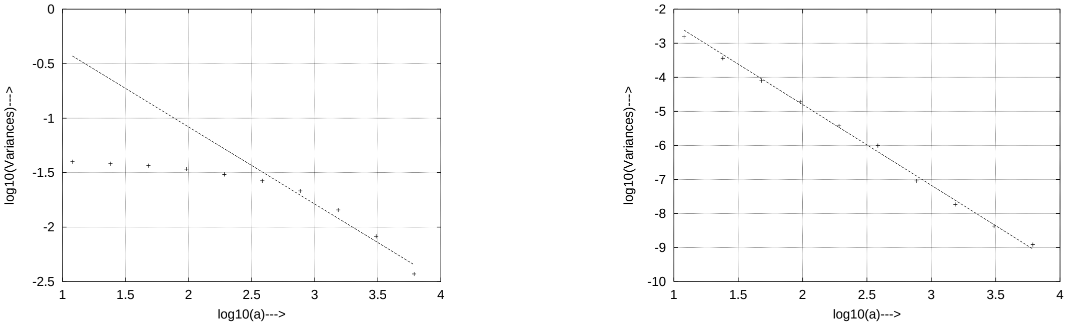
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

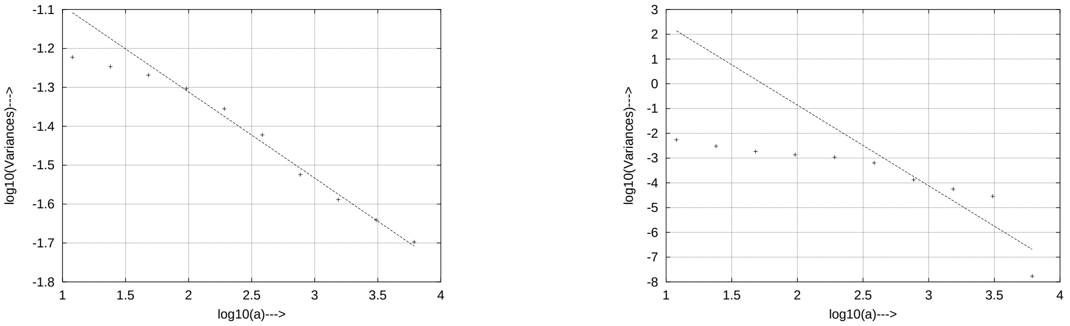
Figure 7: GoP size correlations for the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



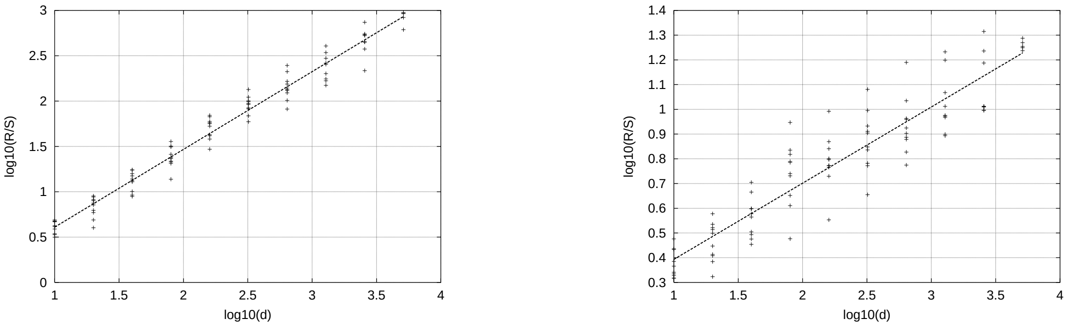
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



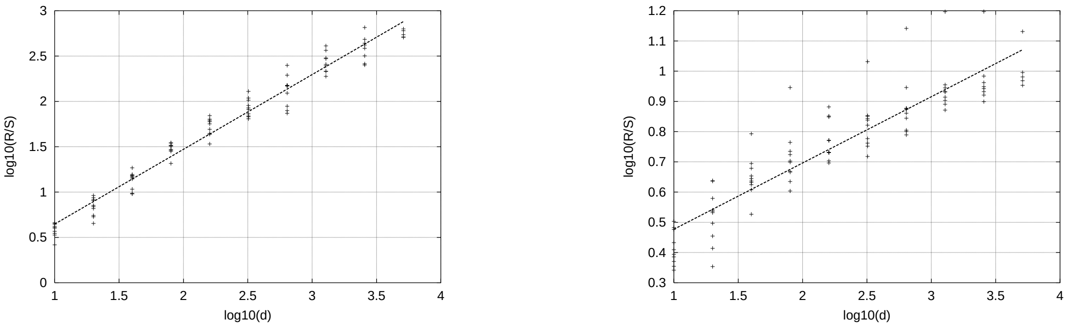
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

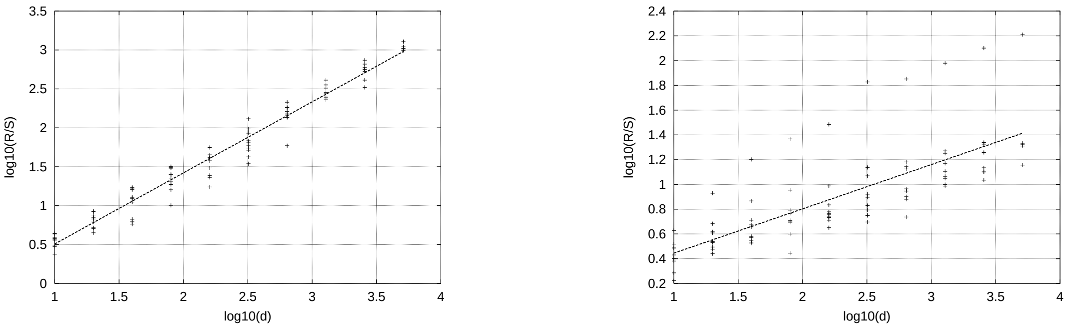
Figure 8: Variance time plots for base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



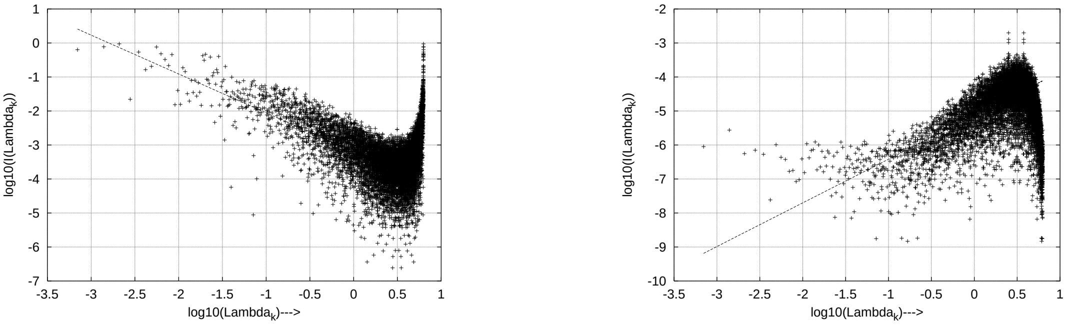
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



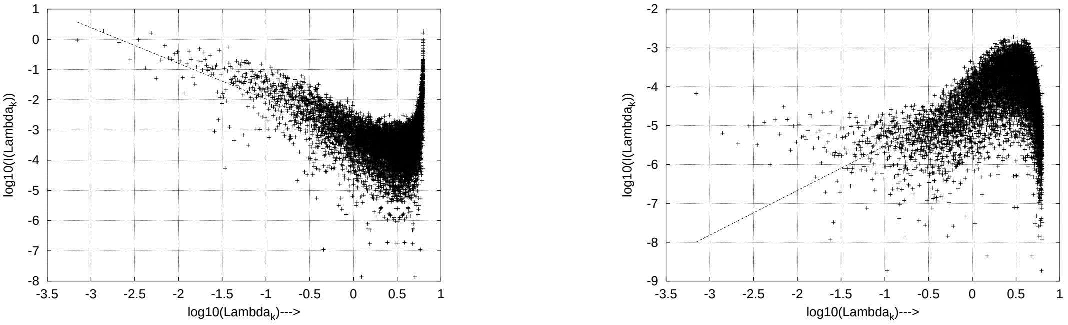
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

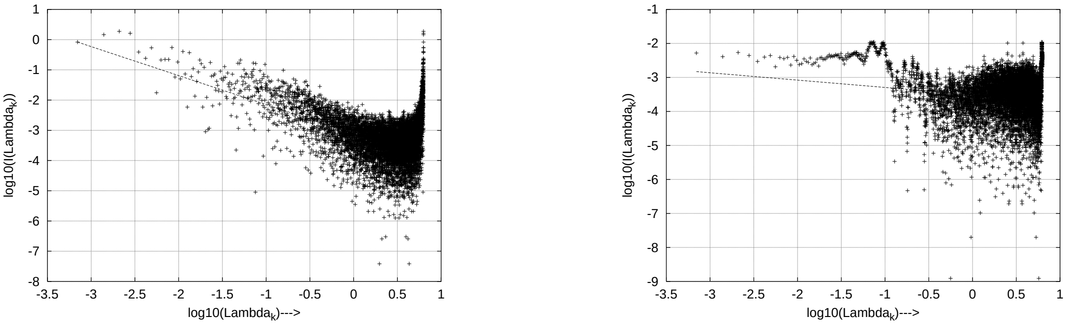
Figure 9: Pox plots of R/S for aggregation level $a = 12$ for base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



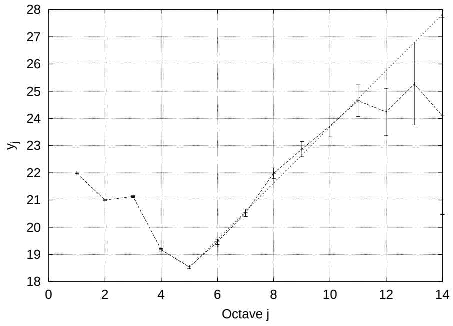
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



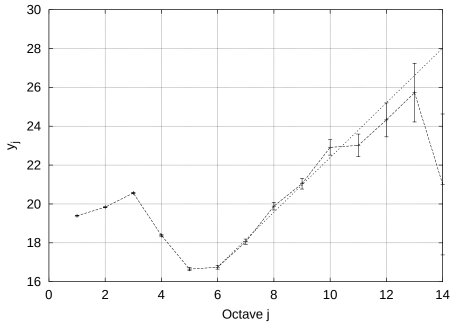
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

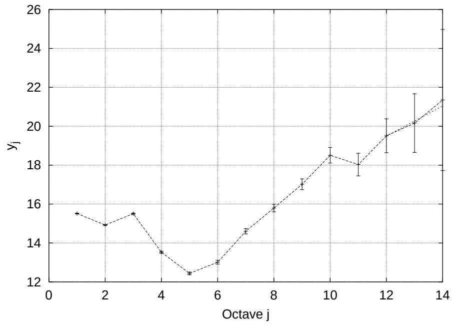
Figure 10: Programs for aggregation level $a = 12$ for base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality

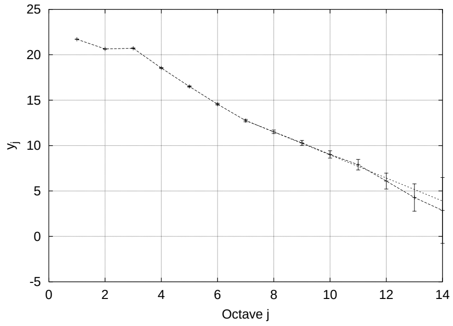


b) *Jurassic Park I* with medium quality

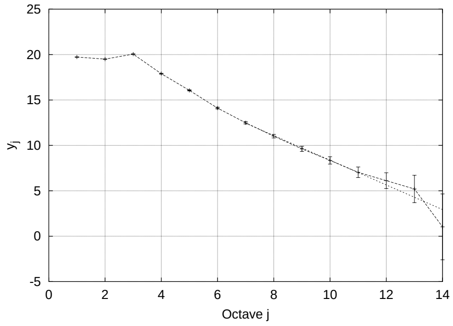


c) *Silence of the Lambs* with low quality

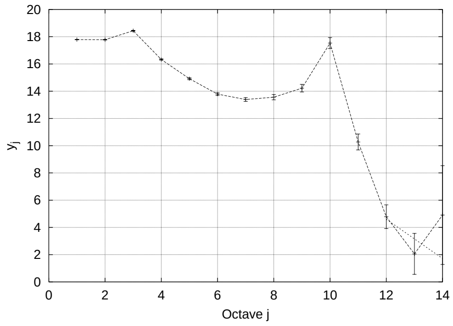
Encoding without rate control



d) *Star Wars IV* with 256 kbps target bit rate



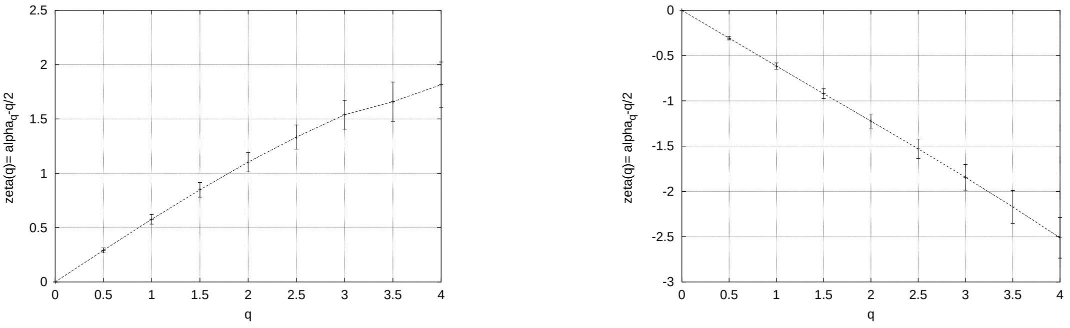
e) *Jurassic Park I* with 128 kbps target bit rate



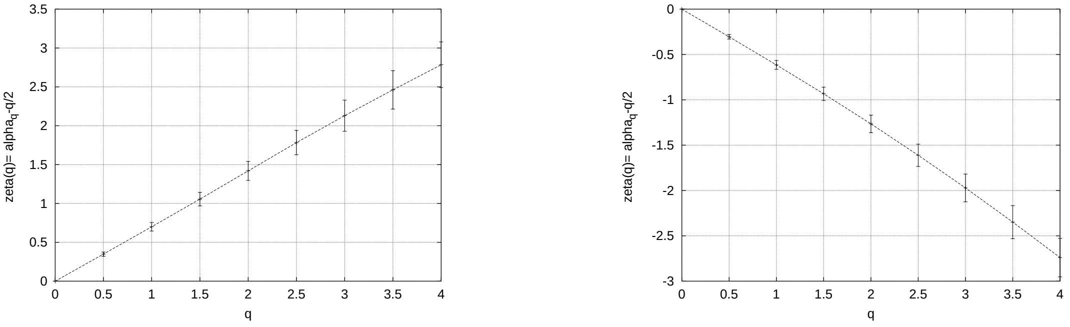
f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding with rate control

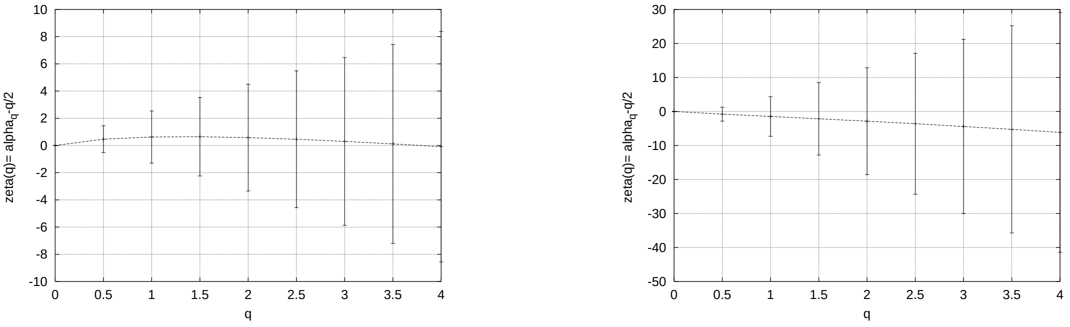
Figure 11: Logscale diagrams for base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



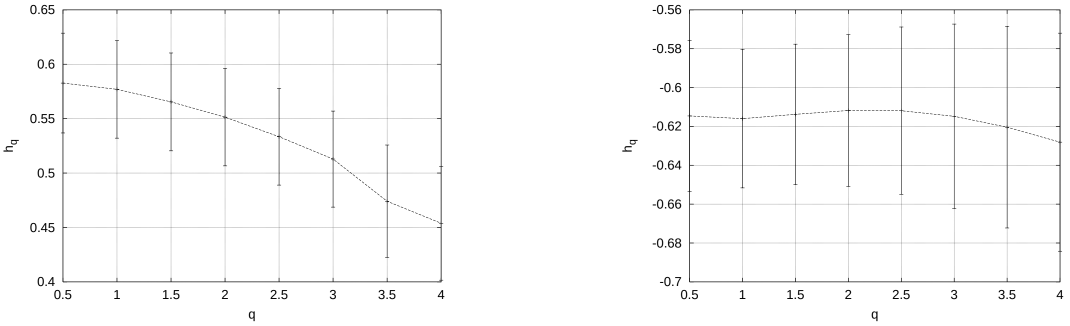
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



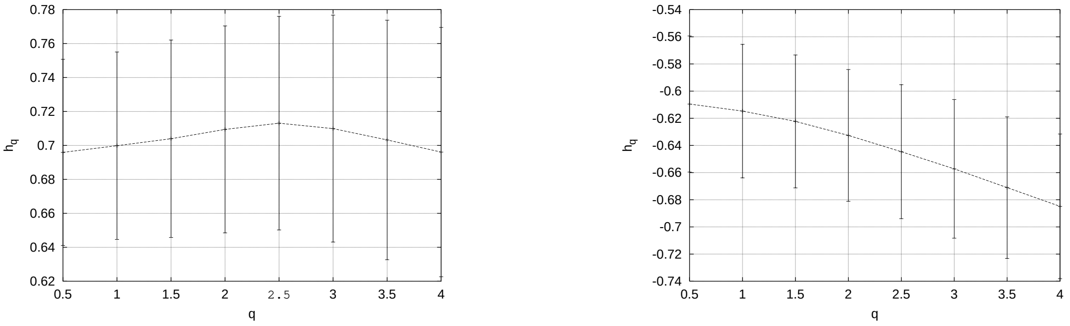
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

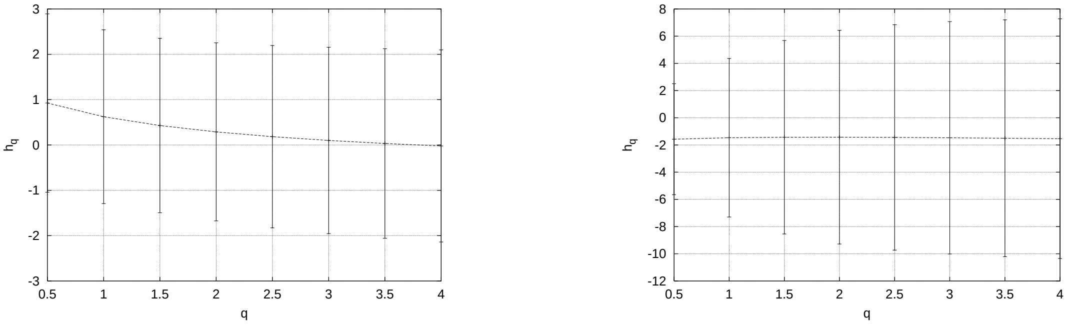
Figure 12: Multi scale diagrams for base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

Figure 13: Linear multi scale diagrams for base layer of temporal scalable QCIF video.

2.2 Enhancement Layer Traffic

Note that with the GoP pattern IBBPBBPBBPBBIBB..., I and P frames make up the base layer and B frames make up the enhancement layer; the enhancement layer frame sizes, X^e_{3k}, are zero, and the enhancement layer frame sizes, X^e_{3k+1} and X^e_{3k+2}, $k = 0, \ldots, N/3 - 1$ are nonzero.

Table 7 gives the mean frame sizes ($\bar{X}^e$), the coefficients of variation (CoV^e_X), and the peak-to-mean ratios ($X^e_{\max}/\bar{X}^e$) of the enhancement layer frame sizes along with the mean bit rate ($\bar{X}^e/T$) and the peak bit rate ($X^e_{\max}/T$).

Table 7: Overview of frame statistics of the enhancement layer of temporal scalable encoded video

		Frame Size			Bit Rate	
Enc. M.	Video	Mean $\bar{X}^e$ [kbyte]	CoV CoV^e_X	Peak/Mean $X^e_{\max}/\bar{X}^e$	Mean $\bar{X}^e/T$ [Mbps]	Peak $X^e_{\max}/T$ [Mbps]
QCIF	*Citizen Kane*	0.914	1.152	10.792	0.219	2.368
H.Q.	*Die Hard I*	1.483	0.844	7.030	0.356	2.502
No R.C.	*Jurassic Park I*	1.685	1.003	10.382	0.404	4.198
	Silence of the Lambs	0.986	1.088	14.820	0.237	3.508
	Star Wars IV	1.203	0.893	11.815	0.289	3.411
	Star Wars V	1.921	0.885	7.830	0.461	3.610
	The Firm	1.346	0.953	8.459	0.323	2.733
	Terminator I	1.550	1.002	15.765	0.372	5.865
	Total Recall	1.515	0.872	6.974	0.364	2.536
	Aladdin	3.172	0.828	6.874	0.761	5.233
	Cinderella	2.135	0.929	11.672	0.512	5.981
	Baseball with Comm	2.379	0.801	4.885	0.571	2.789
	Snowboard with Comm	2.739	0.884	9.336	0.657	6.138
	Oprah w/o Comm	3.329	0.843	3.987	0.799	3.185
	Tonight Show w/o Comm	1.442	1.175	11.567	0.346	4.003
	Lecture-Gupta	3.116	0.760	4.291	0.748	3.209
	Lecture-Reisslein	3.446	0.846	4.463	0.827	3.691
QCIF	*Jurassic Park I*	0.407	1.244	17.797	0.098	1.738
H.–M.Q.	*Star Wars IV*	0.262	1.130	23.240	0.063	1.459
No R.C.	*The Firm*	0.278	1.293	15.736	0.067	1.050
	Tonight Show w/o Comm	0.296	1.439	23.710	0.071	1.687
QCIF	*Citizen Kane*	0.101	1.515	22.487	0.024	0.547
M.Q.	*Die Hard I*	0.164	1.248	17.062	0.039	0.671
No R.C.	*Jurassic Park I*	0.164	1.428	23.106	0.039	0.911
	Silence of the Lambs	0.108	1.545	34.874	0.026	0.905
	Star Wars IV	0.127	1.246	29.700	0.030	0.904
	Star Wars V	0.162	1.287	23.170	0.039	0.900
	The Firm	0.118	1.435	18.717	0.028	0.531
	Terminator I	0.217	1.333	33.876	0.052	1.762
	Total Recall	0.156	1.281	19.507	0.037	0.730
	Aladdin	0.310	1.293	19.627	0.074	1.458
	Cinderella	0.212	1.415	34.952	0.051	1.778
	Baseball with Comm	0.203	1.156	14.714	0.049	0.717
	Snowboard with Comm	0.317	1.093	22.882	0.076	1.740
	Oprah w/o Comm	0.254	1.037	10.662	0.061	0.651
	Tonight Show w/o Comm	0.105	1.773	37.224	0.025	0.937
	Lecture-Gupta	0.260	0.838	13.258	0.062	0.827
	Lecture-Reisslein	0.292	0.921	12.356	0.070	0.865
QCIF	*Jurassic Park I*	0.127	1.172	17.378	0.031	0.531
M.–L.Q.	*Star Wars IV*	0.111	1.103	22.303	0.027	0.594
No R.C.	*The Firm*	0.104	1.170	12.393	0.025	0.310

Table 7: *continued*

		Frame Size			Bit Rate	
		Mean	CoV	Peak/Mean	Mean	Peak
Enc. M.	Video	$\bar{X}^e$ [kbyte]	CoV_X^e	$X^e_{\max}/\bar{X}^e$	$\bar{X}^e/T$ [Mbps]	$X^e_{\max}/T$ [Mbps]
	Tonight Show w/o Comm	0.082	1.486	28.648	0.020	0.565
QCIF	*Citizen Kane*	0.087	1.121	14.525	0.021	0.303
L.Q.	*Die Hard I*	0.129	1.049	12.931	0.031	0.399
No R.C.	*Jurassic Park I*	0.111	1.096	17.852	0.027	0.476
	Silence of the Lambs	0.103	1.105	16.089	0.025	0.396
	Star Wars IV	0.104	1.046	18.613	0.025	0.467
	Star Wars V	0.116	1.062	17.940	0.028	0.499
	The Firm	0.098	1.094	9.637	0.023	0.226
	Terminator I	0.147	1.094	23.318	0.035	0.825
	Total Recall	0.121	1.074	15.056	0.029	0.438
	Aladdin	0.168	1.120	17.315	0.040	0.697
	Cinderella	0.140	1.106	24.727	0.034	0.829
	Baseball with Comm	0.136	1.042	13.065	0.033	0.426
	Snowboard with Comm	0.183	0.978	17.339	0.044	0.762
	Oprah w/o Comm	0.116	0.995	10.183	0.028	0.283
	Tonight Show w/o Comm	0.073	1.353	23.717	0.018	0.417
	Lecture-Gupta	0.113	0.854	16.022	0.027	0.436
	Lecture-Reisslein	0.121	0.922	13.695	0.029	0.397
QCIF	*Citizen Kane*	0.162	1.574	18.505	0.039	0.720
R.C.	*Die Hard I*	0.245	1.175	11.529	0.059	0.678
64 kbps	*Jurassic Park I*	0.300	1.292	13.298	0.072	0.956
	Silence of the Lambs	0.153	1.601	26.351	0.037	0.969
	Star Wars IV	0.183	1.344	23.048	0.044	1.011
	Star Wars V	0.288	1.290	10.714	0.069	0.741
	The Firm	0.197	1.485	14.499	0.047	0.685
	Terminator I	0.343	1.184	21.499	0.082	1.768
	Total Recall	0.243	1.209	11.930	0.058	0.696
	Aladdin	0.547	1.038	11.247	0.131	1.476
	Cinderella	0.344	1.188	21.789	0.083	1.801
	Baseball with Comm	0.316	1.070	9.535	0.076	0.724
	Snowboard with Comm	0.539	0.985	13.547	0.129	1.753
	Oprah w/o Comm	0.365	1.023	8.996	0.088	0.789
	Tonight Show w/o Comm	0.242	1.337	19.095	0.058	1.110
	Lecture-Gupta	0.423	0.986	8.177	0.101	0.830
	Lecture-Reisslein	0.556	0.976	6.296	0.133	0.840
QCIF	*Citizen Kane*	0.119	1.525	21.587	0.029	0.616
R.C.	*Die Hard I*	0.176	1.208	16.727	0.042	0.705
128 kbps	*Jurassic Park I*	0.186	1.547	21.172	0.045	0.944
	Silence of the Lambs	0.131	1.487	30.774	0.031	0.969
	Star Wars IV	0.141	1.302	28.584	0.034	0.968
	Star Wars V	0.201	1.311	14.577	0.048	0.705
	The Firm	0.140	1.415	19.319	0.034	0.649
	Terminator I	0.236	1.325	31.044	0.057	1.759
	Total Recall	0.167	1.239	18.334	0.040	0.737
	Aladdin	0.388	1.234	15.867	0.093	1.476
	Cinderella	0.242	1.368	31.076	0.058	1.804
	Baseball with Comm	0.232	1.104	13.012	0.056	0.724
	Snowboard with Comm	0.385	1.088	18.713	0.092	1.729
	Oprah w/o Comm	0.276	1.073	11.475	0.066	0.761
	Tonight Show w/o Comm	0.173	1.370	25.038	0.041	1.038
	Lecture-Gupta	0.323	0.918	10.704	0.077	0.829
	Lecture-Reisslein	0.393	0.942	8.828	0.094	0.833
QCIF	*Citizen Kane*	0.110	1.350	21.357	0.026	0.561
R.C.	*Die Hard I*	0.166	1.174	18.075	0.040	0.722
256 kbps	*Jurassic Park I*	0.152	1.530	25.357	0.036	0.924
	Silence of the Lambs	0.124	1.337	31.711	0.030	0.945
	Star Wars IV	0.129	1.198	29.642	0.031	0.920
	Star Wars V	0.168	1.223	17.121	0.040	0.690
	The Firm	0.124	1.288	19.056	0.030	0.565

Table 7: *continued*

		Frame Size			Bit Rate	
		Mean	CoV	Peak/Mean	Mean	Peak
Enc. M.	Video	$\bar{X}^e$ [kbyte]	CoV_X^e	$X^e_{\max}/\bar{X}^e$	$\bar{X}^e/T$ [Mbps]	$X^e_{\max}/T$ [Mbps]
	Terminator I	0.209	1.339	35.284	0.050	1.766
	Total Recall	0.153	1.223	20.262	0.037	0.744
	Aladdin	0.316	1.300	19.408	0.076	1.471
	Cinderella	0.212	1.410	35.494	0.051	1.807
	Baseball with Comm	0.208	1.098	14.599	0.050	0.728
	Snowboard with Comm	0.320	1.078	22.427	0.077	1.721
	Oprah w/o Comm	0.244	1.060	12.027	0.059	0.705
	Tonight Show w/o Comm	0.140	1.311	28.350	0.034	0.955
	Lecture-Gupta	0.270	0.828	12.847	0.065	0.833
	Lecture-Reisslein	0.315	0.848	11.363	0.076	0.859

We consider two smoothed versions of the enhancement layer trace. We define the two-frame smoothed enhancement layer trace $O_n^e,\ n = 0, \ldots, N-1$, as follows. $O_{3k}^e = O_{3k+1}^e = X_{3k+1}^e/2$ and $O_{3k+2}^e = X_{3k+2}^e$ for $k = 0, \ldots, N/3 - 1$. We define the three-frame smoothed enhancement layer trace $P_n^e,\ n = 0, \ldots, N-1$, as $P_{3k}^e = P_{3k+1}^e = P_{3k+2}^e = (X_{3k+1}^e + X_{3k+1}^e)/3$ for $k = 0, \ldots, N/3-1$. (Note that the statistical analysis of $P_n^e,\ n = 0, \ldots, N-1$, is equivalent to the statistical analysis of the aggregated enhancement layer trace with aggregation level $a = 3$, i.e., $X_n^{e(3)},\ n = 0, \ldots, N/3 - 1$.)

Table 8 gives the coefficients of variation (CoV_O^e and CoV_P^p), the peak-to-mean ratios ($O_{\max}^e/\bar{X}^e$ and $P_{\max}^e/\bar{X}^e$) along with the peak bit rates ($O_{\max}^e/T$ and $P_{\max}^e/T$) of the smoothed traces.

Table 8: Overview of frame statistics of the smoothed enhancement layer of temporal scalable encoded video

		Frame Size				Bit Rate	
		CoV		Peak/Mean		Peak	
Enc. M.	Video	CoV_O^e	CoV_P^e	$O_{\max}^e/\bar{X}^e$	$P_{\max}^e/\bar{X}^e$	$O_{\max}^e/T$ [Mbps]	$P_{\max}^e/T$ [Mbps]
QCIF	*Citizen Kane*	0.867	0.708	10.792	6.842	2.368	1.501
H.Q.	*Die Hard I*	0.535	0.354	7.030	4.392	2.502	1.563
No R.C.	*Jurassic Park I*	0.712	0.557	10.382	6.886	4.198	2.784
	Silence of the Lambs	0.801	0.661	14.820	9.738	3.508	2.305
	Star Wars IV	0.592	0.428	11.815	7.769	3.411	2.243
	Star Wars V	0.583	0.417	7.830	4.909	3.610	2.264
	The Firm	0.660	0.506	8.440	5.547	2.727	1.793
	Terminator I	0.711	0.534	15.765	7.214	5.865	2.684
	Total Recall	0.568	0.396	6.974	4.451	2.536	1.618
	Aladdin	0.514	0.338	6.668	4.501	5.077	3.427
	Cinderella	0.632	0.479	11.672	7.234	5.981	3.706
	Baseball with Comm	0.483	0.305	4.771	3.219	2.724	1.838
	Snowboard with Comm	0.581	0.430	9.336	5.826	6.138	3.830
	Oprah w/o Comm	0.534	0.375	3.982	2.656	3.181	2.122
	Tonight Show w/o Comm	0.890	0.765	11.567	6.817	4.003	2.359
	Lecture-Gupta	0.429	0.226	4.291	2.494	3.209	1.865
	Lecture-Reisslein	0.536	0.379	4.104	2.635	3.394	2.179
QCIF	*Jurassic Park One*	0.956	0.802	17.765	11.854	1.735	1.158
H–M.Q.	*Star Wars IV*	0.842	0.687	22.869	15.070	1.436	0.946
No R.C.	*The Firm*	1.004	0.855	14.974	10.238	1.000	0.683
	Tonight Show w/o Comm	1.146	1.018	23.710	13.085	1.687	0.931
QCIF	*Citizen Kane*	1.213	1.044	22.487	14.637	0.547	0.356
M.Q.	*Die Hard I*	0.956	0.789	16.525	10.901	0.650	0.429
No R.C.	*Jurassic Park I*	1.130	0.965	23.106	15.368	0.911	0.606
	Silence of the Lambs	1.239	1.083	34.717	22.732	0.900	0.590
	Star Wars IV	0.952	0.796	25.040	16.486	0.762	0.502
	Star Wars V	0.995	0.830	23.170	14.594	0.900	0.567
	The Firm	1.136	0.981	18.505	12.157	0.525	0.345
	Terminator I	1.039	0.851	33.876	14.249	1.762	0.741
	Total Recall	0.988	0.823	17.435	10.531	0.652	0.394
	Aladdin	1.000	0.834	18.245	12.460	1.356	0.926
	Cinderella	1.118	0.953	34.952	22.658	1.778	1.153
	Baseball with Comm	0.866	0.732	14.714	9.688	0.717	0.472
	Snowboard with Comm	0.804	0.669	22.882	13.613	1.740	1.035
	Oprah w/o Comm	0.748	0.615	10.662	7.041	0.651	0.430
	Tonight Show w/o Comm	1.452	1.319	37.224	19.594	0.937	0.493
	Lecture-Gupta	0.529	0.354	13.258	7.319	0.827	0.456
	Lecture-Reisslein	0.626	0.476	10.094	6.891	0.707	0.482
QCIF	*Jurassic Park One*	0.880	0.739	17.378	11.419	0.531	0.349

Table 8: *continued*

		Frame Size				Bit Rate	
		CoV		Peak/Mean		Peak	
Enc. M.	Video	CoV_O^e	CoV_P^e	$O^e_{\max}/\bar{X}^e$	$P^e_{\max}/\bar{X}^e$	$O^e_{\max}/T$ [Mbps]	$P^e_{\max}/T$ [Mbps]
M–L.Q.	*Star Wars IV*	0.809	0.669	19.647	10.701	0.524	0.285
No R.C.	*The Firm*	0.878	0.745	12.393	7.150	0.310	0.179
	Tonight Show w/o Comm	1.184	1.061	28.648	14.029	0.565	0.277
QCIF	*Citizen Kane*	0.829	0.697	14.525	9.377	0.303	0.196
L.Q.	*Die Hard I*	0.754	0.612	12.931	7.945	0.399	0.245
No R.C.	*Jurassic Park I*	0.802	0.667	17.726	11.860	0.473	0.317
	Silence of the Lambs	0.814	0.683	15.953	10.526	0.393	0.259
	Star Wars IV	0.750	0.613	17.934	7.790	0.450	0.195
	Star Wars V	0.769	0.627	16.060	10.708	0.447	0.298
	The Firm	0.800	0.671	9.637	5.639	0.226	0.132
	Terminator I	0.801	0.647	23.318	10.299	0.825	0.365
	Total Recall	0.780	0.640	13.777	7.821	0.401	0.228
	Aladdin	0.829	0.680	15.443	10.826	0.622	0.436
	Cinderella	0.815	0.673	23.388	15.923	0.784	0.534
	Baseball with Comm	0.748	0.615	13.065	8.541	0.426	0.279
	Snowboard with Comm	0.682	0.544	17.339	10.076	0.762	0.443
	Oprah w/o Comm	0.702	0.568	10.123	6.769	0.281	0.188
	Tonight Show w/o Comm	1.057	0.937	23.717	10.706	0.417	0.188
	Lecture-Gupta	0.548	0.381	16.022	7.742	0.436	0.210
	Lecture-Reisslein	0.623	0.478	11.673	7.556	0.338	0.219
QCIF	*Citizen Kane*	1.271	1.140	18.369	12.224	0.715	0.476
R.C.	*Die Hard I*	0.888	0.755	10.913	7.297	0.642	0.429
64 kbps	*Jurassic Park I*	1.003	0.879	13.132	8.810	0.944	0.634
	Silence of the Lambs	1.294	1.166	26.351	17.543	0.969	0.645
	Star Wars IV	1.053	0.921	22.124	14.750	0.971	0.647
	Star Wars V	1.003	0.874	10.714	6.718	0.741	0.465
	The Firm	1.187	1.061	14.499	9.260	0.685	0.437
	Terminator I	0.896	0.763	21.499	9.046	1.768	0.744
	Total Recall	0.921	0.791	11.111	6.925	0.648	0.404
	Aladdin	0.748	0.613	10.234	7.101	1.343	0.932
	Cinderella	0.900	0.771	21.577	13.995	1.784	1.157
	Baseball with Comm	0.783	0.651	9.317	6.129	0.707	0.465
	Snowboard with Comm	0.693	0.557	13.547	8.195	1.753	1.060
	Oprah w/o Comm	0.736	0.602	8.996	5.991	0.789	0.525
	Tonight Show w/o Comm	1.047	0.925	19.095	10.317	1.110	0.599
	Lecture-Gupta	0.694	0.560	8.177	4.489	0.830	0.456
	Lecture-Reisslein	0.682	0.548	5.301	3.496	0.707	0.467
QCIF	*Citizen Kane*	1.225	1.076	21.587	14.055	0.616	0.401
R.C.	*Die Hard I*	0.918	0.757	16.727	10.305	0.705	0.434
128 kbps	*Jurassic Park I*	1.244	1.103	20.994	14.055	0.936	0.627
	Silence of the Lambs	1.187	1.052	30.774	20.409	0.969	0.643
	Star Wars IV	1.011	0.862	28.584	18.964	0.968	0.642
	Star Wars V	1.024	0.876	14.577	8.974	0.705	0.434
	The Firm	1.120	0.979	19.319	12.290	0.649	0.413
	Terminator I	1.033	0.869	31.044	13.100	1.759	0.742
	Total Recall	0.948	0.789	16.274	10.006	0.654	0.402
	Aladdin	0.945	0.804	14.438	10.018	1.343	0.932
	Cinderella	1.075	0.931	30.749	19.958	1.785	1.159
	Baseball with Comm	0.816	0.681	13.012	8.544	0.724	0.476
	Snowboard with Comm	0.801	0.669	18.713	11.288	1.729	1.043
	Oprah w/o Comm	0.787	0.655	11.475	7.639	0.761	0.507
	Tonight Show w/o Comm	1.079	0.954	25.038	14.162	1.038	0.587
	Lecture-Gupta	0.621	0.472	10.704	5.916	0.829	0.458
	Lecture-Reisslein	0.648	0.505	7.487	5.298	0.706	0.500
QCIF	*Citizen Kane*	1.059	0.892	21.357	13.867	0.561	0.364
R.C.	*Die Hard I*	0.885	0.708	18.075	10.871	0.722	0.434
256 kbps	*Jurassic Park I*	1.226	1.063	25.344	16.901	0.923	0.616
	Silence of the Lambs	1.043	0.894	31.711	20.714	0.945	0.617
	Star Wars IV	0.908	0.743	29.642	19.669	0.920	0.611

Table 8: *continued*

		Frame Size				Bit Rate	
		CoV		Peak/Mean		Peak	
Enc. M.	Video	CoV_O^e	CoV_P^e	$O_{\max}^e/\bar{X}^e$	$P_{\max}^e/\bar{X}^e$	$O_{\max}^e/T$ [Mbps]	$P_{\max}^e/T$ [Mbps]
	Star Wars V	0.937	0.764	17.121	10.833	0.690	0.436
	The Firm	0.996	0.837	17.608	12.223	0.522	0.363
	Terminator I	1.046	0.852	35.284	14.874	1.766	0.744
	Total Recall	0.932	0.757	18.275	10.796	0.671	0.396
	Aladdin	1.008	0.844	17.897	12.228	1.356	0.927
	Cinderella	1.114	0.950	34.929	22.745	1.778	1.158
	Baseball with Comm	0.807	0.670	14.599	9.672	0.728	0.483
	Snowboard with Comm	0.789	0.652	22.427	13.428	1.721	1.030
	Oprah w/o Comm	0.770	0.641	12.027	8.018	0.705	0.470
	Tonight Show w/o Comm	1.019	0.894	28.350	16.734	0.955	0.564
	Lecture-Gupta	0.517	0.339	12.847	7.014	0.833	0.455
	Lecture-Reisslein	0.540	0.375	9.675	6.719	0.732	0.508

Table 9 gives the mean GoP sizes ($\bar{Y}^e$), the coefficients of variation of the GoP sizes (CoV_Y^e), and the peak-to-mean ratios ($Y_{\max}^e/\bar{Y}^e$) of the GoP sizes, as well as the peak bit rates ($Y_{\max}^b/(GT)$).

Table 9: Overview of GoP statistics of the enhancement layer of temporal scalable encoded video

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}$	CoV_Y	$Y_{\max}/\bar{Y}$	$Y_{\max}/(GT)$ [Mbps]
QCIF	*Citizen Kane*	10.971	0.663	5.717	1.254
H.Q.	*Die Hard I*	17.791	0.320	2.845	1.012
No R.C.	*Jurassic Park I*	20.217	0.523	5.843	2.362
	Silence of the Lambs	11.835	0.640	8.831	2.090
	Star Wars IV	14.437	0.398	5.751	1.660
	Star Wars V	23.054	0.392	3.110	1.434
	The Firm	16.157	0.482	4.785	1.546
	Terminator I	18.602	0.479	4.868	1.811
	Total Recall	18.178	0.364	3.698	1.344
	Aladdin	38.067	0.299	3.094	2.356
	Cinderella	25.620	0.447	6.223	3.188
	Baseball with Comm	28.549	0.291	2.759	1.576
	Snowboard with Comm	32.871	0.414	4.629	3.043
	Oprah w/o Comm	39.945	0.372	2.113	1.688
	Tonight Show w/o Comm	17.305	0.757	5.454	1.887
	Lecture-Gupta	37.392	0.222	2.043	1.528
	Lecture-Reisslein	41.347	0.377	2.282	1.887
QCIF	*Jurassic Park I*	4.884	0.751	9.369	0.915
H.–M.Q.	*Star Wars IV*	3.139	0.620	10.166	0.638
No R.C.	*The Firm*	3.338	0.808	7.907	0.528
	Tonight Show w/o Comm	3.557	0.992	9.493	0.675
QCIF	*Citizen Kane*	1.216	0.923	8.648	0.210
M.Q.	*Die Hard I*	1.967	0.693	5.223	0.205
No R.C.	*Jurassic Park I*	1.971	0.888	11.642	0.459
	Silence of the Lambs	1.297	0.989	20.066	0.520
	Star Wars IV	1.522	0.686	10.474	0.319
	Star Wars V	1.941	0.729	6.983	0.271
	The Firm	1.418	0.896	9.140	0.259
	Terminator I	2.600	0.750	8.477	0.441
	Total Recall	1.871	0.732	6.552	0.245
	Aladdin	3.715	0.690	7.002	0.520
	Cinderella	2.544	0.831	16.794	0.854
	Baseball with Comm	2.437	0.666	6.711	0.327

Table 9: *continued*

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}$	CoV_Y	$Y_{\max}/\bar{Y}$	$Y_{\max}/(GT)$ [Mbps]
	Snowboard with Comm	3.802	0.619	8.988	0.683
	Oprah w/o Comm	3.053	0.601	4.877	0.298
	Tonight Show w/o Comm	1.259	1.258	12.972	0.327
	Lecture-Gupta	3.118	0.321	3.718	0.232
	Lecture-Reisslein	3.500	0.446	5.257	0.368
QCIF M.–L.Q. No R.C.	*Jurassic Park I*	1.527	0.676	7.521	0.230
	Star Wars IV	1.333	0.556	7.060	0.188
	The Firm	1.252	0.640	5.740	0.144
	Tonight Show w/o Comm	0.986	0.986	8.683	0.171
QCIF L.Q. No R.C.	*Citizen Kane*	1.044	0.541	4.593	0.096
	Die Hard I	1.543	0.532	3.905	0.121
	Jurassic Park I	1.334	0.598	5.601	0.149
	Silence of the Lambs	1.232	0.534	9.278	0.229
	Star Wars IV	1.254	0.496	5.227	0.131
	Star Wars V	1.391	0.521	5.266	0.147
	The Firm	1.170	0.545	4.258	0.100
	Terminator I	1.770	0.564	6.020	0.213
	Total Recall	1.455	0.558	4.847	0.141
	Aladdin	2.013	0.556	5.845	0.235
	Cinderella	1.676	0.571	11.155	0.374
	Baseball with Comm	1.631	0.535	5.338	0.174
	Snowboard with Comm	2.196	0.490	6.543	0.287
	Oprah w/o Comm	1.389	0.504	4.610	0.128
	Tonight Show w/o Comm	0.880	0.828	6.920	0.122
	Lecture-Gupta	1.359	0.265	4.005	0.109
	Lecture-Reisslein	1.448	0.396	5.855	0.170
QCIF R.C. 64 kbps	*Citizen Kane*	1.946	1.103	10.671	0.415
	Die Hard I	2.940	0.720	4.521	0.266
	Jurassic Park I	3.596	0.858	7.661	0.551
	Silence of the Lambs	1.839	1.142	16.430	0.604
	Star Wars IV	2.194	0.885	11.228	0.493
	Star Wars V	3.457	0.849	5.123	0.354
	The Firm	2.362	1.035	8.326	0.393
	Terminator I	4.112	0.731	5.907	0.486
	Total Recall	2.916	0.761	5.573	0.325
	Aladdin	6.563	0.573	4.786	0.628
	Cinderella	4.133	0.731	11.144	0.921
	Baseball with Comm	3.796	0.620	5.030	0.382
	Snowboard with Comm	6.470	0.530	5.755	0.745
	Oprah w/o Comm	4.386	0.585	4.665	0.409
	Tonight Show w/o Comm	2.905	0.896	7.478	0.435
	Lecture-Gupta	5.073	0.533	3.860	0.392
	Lecture-Reisslein	6.671	0.535	3.042	0.406
QCIF R.C. 128 kbps	*Citizen Kane*	1.426	1.019	13.338	0.381
	Die Hard I	2.108	0.684	5.998	0.253
	Jurassic Park I	2.229	1.062	12.045	0.537
	Silence of the Lambs	1.575	1.023	19.154	0.603
	Star Wars IV	1.694	0.801	13.940	0.472
	Star Wars V	2.418	0.825	6.346	0.307
	The Firm	1.680	0.939	10.778	0.362
	Terminator I	2.833	0.798	8.546	0.484
	Total Recall	2.009	0.719	6.919	0.278
	Aladdin	4.652	0.735	6.751	0.628
	Cinderella	2.903	0.853	15.834	0.919
	Baseball with Comm	2.783	0.634	6.533	0.364
	Snowboard with Comm	4.619	0.637	7.799	0.720
	Oprah w/o Comm	3.315	0.640	5.783	0.383
	Tonight Show w/o Comm	2.072	0.929	10.045	0.416
	Lecture-Gupta	3.873	0.455	4.424	0.343

Table 9: *continued*

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}$	CoV_Y	$Y_{\max}/\bar{Y}$	$Y_{\max}/(GT)$ [Mbps]
	Lecture-Reisslein	4.717	0.495	3.975	0.375
QCIF	*Citizen Kane*	1.314	0.814	8.968	0.236
R.C.	*Die Hard I*	1.996	0.621	5.131	0.205
256 kbps	*Jurassic Park I*	1.822	0.995	13.328	0.486
	Silence of the Lambs	1.489	0.852	18.692	0.557
	Star Wars IV	1.553	0.658	13.648	0.424
	Star Wars V	2.014	0.677	6.816	0.275
	The Firm	1.483	0.777	9.219	0.273
	Terminator I	2.502	0.751	8.921	0.446
	Total Recall	1.836	0.669	6.728	0.247
	Aladdin	3.790	0.711	7.184	0.544
	Cinderella	2.545	0.834	17.555	0.894
	Baseball with Comm	2.495	0.613	6.607	0.330
	Snowboard with Comm	3.836	0.608	9.118	0.700
	Oprah w/o Comm	2.931	0.628	5.937	0.348
	Tonight Show w/o Comm	1.684	0.862	10.438	0.352
	Lecture-Gupta	3.242	0.310	3.718	0.241
	Lecture-Reisslein	3.782	0.357	5.081	0.384

The main features of the temporal enhancement layer traffic without rate control are summarized as follows:

- A very pronounced "hump" in the variability at the medium quality level.
- A relatively large variability compared to the single layer encodings, which, as noted above, is due to the wide range of sizes for the B frames.

The main features of the temporal enhancement layer traffic corresponding to the rate-controlled base layer are:

- The mean bit rate of the enhancement layer decreases as the target bit rate of the base layer increases. This is clearly expected as the higher bit rate base layer contains a more accurate encoding of the video, leaving less video information to be encoded in the enhancement layer.
- A somewhat higher variability compared to the medium quality single layer encoding (which uses the same quantization parameters as the enhancement layer of the rate-controlled base layer.).
- A slight tendency of the enhancement layer traffic to become more variable as the base layer target bit rate increases.
- About the same level of variability as the enhancement layer at the medium quality level without rate control.

Figure 14 gives the (unsmoothed) frame size X_n^e (in bytes) as a function of the frame number n. Figure 15 gives the GoP size Y_m^e (in bytes) as a function of the GoP number m. The high variability of the enhancement layer traffic is also reflected in these frame size and GoP size plots. Notice in particular the high variability of the enhancement layer as the rate-controlled encodings as well as the similarities between the *Jurassic Park I* enhancement layers with and without rate control for the base layer.

In the following analysis we focus on the 3-frame smoothed frame size trace P_n^e, $n = 0, \ldots, N-1$; for conciseness, we analyze the statistically equivalent trace $X_n^{e(3)}$, $n = 0, \ldots, N/3-1$.

Figure 16 gives the histograms of the frame sizes $X_n^{e(3)}$. Note that the histograms for the enhancement layers that correspond to the rate-controlled base layers are cut off at a frame size of 3000 bytes for ease of comparison and thus, do not include the rare extremely large frames.

Figure 18 gives the autocorrelation coefficient $\rho^e_{X^{(3)}}(k)$ of the frame size sequence $X_n^{e(3)}$, $n = 0, \ldots, N/3-1$, as a function of the lag k (in frames). For almost all of the encodings without rate control we observe periodic oscillations of the autocorrelation function, which are especially pronounced for the low quality encodings, with a period of 12 frames (i.e., one GoP). The explanation of this phenomenon is as follows. B frames are generally encoded with respect to the I or P frame that has the smallest difference (on a macro-block basis). For the last 2 two B frames in a GoP, the following I frame is typically chosen as the reference. This I frame typically gives smaller differences because the other alternative — the P frame preceding the last two B frames in the GoP — tends to accumulate forward prediction error throughout the GoP. Encoding the last two B frames with respect to the next I frame, however, requires a new set of (absolute) motion vectors, whereas the preceding B frames in the GoP are typically encoded with respect to the preceeding I and P frames using relative (differential) motion vectors. Since the absolute motion vector require more encoding bits than the differential motion vectors, the last two B frames in the GoP are typically lower, resulting in the periodic spikes in the depicted autocorrelation function.

The underlying trend of the autocorrelation function becomes apparent in Figure 19, which gives the autocorrelation coefficient ($\rho^e_Y(k)$) of the GoP size sequence Y_m^e, $m = 0, \ldots, N/G-1$, as a function of the lag k (in GoPs). The autocorrelations decay quite slowly and remain at a level of 0.1 for lags up to 120 GoPs (i.e., 48 seconds) for *Star Wars IV* and remain at even higher levels for *Silence of the Lambs*. This decay occurs much more rapidly for the *Jurassic Park I* sequence.

Table 10 gives the Hurst parameter obtained with the R/S heuristics and the periodogram for $X_n^e,\ n = 0, \ldots, N-1$, as a function of the aggregation level a.

Table 10: Hurst parameters estimated from pox diagram of R/S and periodogram as a function of the aggregation level a.

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
QCIF	*Citizen Kane*	0.918	0.920	0.894	0.885	0.884	0.886	0.909	0.903	0.847	0.840	0.794
H.Q.	*Citizen Kane*	1.186	1.168	1.162	1.048	0.973	0.902	0.942	0.925	0.899	0.997	0.864
No R.C.	*Die Hard I*	0.787	0.766	0.754	0.738	0.714	0.700	0.653	0.649	0.634	0.610	0.616
	Die Hard I	1.131	1.070	0.994	0.894	0.797	0.764	0.828	0.788	0.756	0.771	0.758
	Jurassic Park I	0.819	0.805	0.773	0.723	0.717	0.707	0.712	0.689	0.662	0.611	0.623
	Jurassic Park I	1.201	1.183	1.102	1.048	1.005	0.953	0.939	0.970	0.923	0.839	0.848
	Silence of the Lambs	0.905	0.887	0.891	0.908	0.917	0.891	0.891	0.801	0.773	0.816	0.743
	Silence of the Lambs	1.236	1.252	1.181	1.068	1.020	1.042	1.013	1.077	1.064	1.075	1.138
	Star Wars IV	0.859	0.853	0.845	0.834	0.825	0.850	0.845	0.851	0.873	0.899	0.875
	Star Wars IV	1.158	1.116	1.068	1.014	0.959	0.937	0.980	0.968	0.974	0.884	1.021
	Star Wars V	0.874	0.844	0.850	0.830	0.817	0.803	0.787	0.844	0.790	0.826	0.760
	Star Wars V	1.247	1.202	1.086	1.009	0.997	0.925	0.894	0.905	0.880	0.811	0.778
	The Firm	0.869	0.854	0.835	0.814	0.804	0.787	0.799	0.742	0.730	0.713	0.673
	The Firm	1.225	1.217	1.143	1.079	1.074	1.001	1.029	0.982	1.038	0.986	0.993
	Terminator I	0.889	0.885	0.870	0.866	0.853	0.858	0.874	0.859	0.841	0.815	0.881
	Terminator I	1.099	1.080	1.036	1.021	0.995	0.995	0.965	1.015	0.968	1.027	0.939
	Total Recall	0.854	0.847	0.831	0.826	0.806	0.800	0.794	0.807	0.797	0.802	0.795
	Total Recall	1.153	1.136	1.048	0.981	0.999	0.932	0.977	0.864	0.895	0.836	0.890
	Aladdin	0.869	0.858	0.864	0.848	0.870	0.871	0.811	0.807	0.786	0.751	0.697
	Aladdin	1.052	1.012	0.953	0.898	0.936	0.937	0.961	0.999	1.107	1.029	1.046
	Cinderella	0.839	0.826	0.841	0.853	0.870	0.872	0.866	0.837	0.865	0.820	0.883
	Cinderella	1.125	1.064	0.987	0.955	0.978	0.975	1.011	1.035	1.000	1.046	1.010
	Baseball with Comm	0.828	0.825	0.801	0.811	0.843	0.862	0.885	0.822	0.830	0.883	0.877
	Baseball with Comm	1.119	1.098	1.021	0.977	0.876	0.791	0.816	0.805	0.808	0.874	0.826
	Snowboard with Comm	0.791	0.773	0.753	0.721	0.700	0.719	0.724	0.739	0.750	0.671	0.739
	Snowboard with Comm	1.196	1.106	0.935	0.944	0.863	0.815	0.778	0.762	0.795	0.686	0.764
	Oprah w/o Comm	0.888	0.877	0.876	0.906	0.919	0.993	0.942	0.992	0.989	0.926	0.930
	Oprah w/o Comm	1.257	1.230	1.145	1.052	1.055	1.104	1.105	1.064	1.034	1.087	1.202
	Tonight Show w/o Comm	0.900	0.917	0.908	0.897	0.887	0.944	0.898	0.959	0.953	0.916	0.962
	Tonight Show w/o Comm	1.162	1.170	1.186	1.212	1.209	1.211	1.245	1.305	1.276	1.320	1.292
	Lecture-Gupta	0.994	0.990	0.976	0.957	0.932	0.970	0.928	0.950	0.957	0.930	0.918
	Lecture-Gupta	1.301	1.243	1.259	1.092	0.903	0.983	1.086	0.984	1.012	1.193	1.229
	Lecture-Reisslein	0.974	0.960	0.944	0.937	0.919	0.895	0.937	0.937	0.881	0.943	0.941
	Lecture-Reisslein	1.303	1.303	1.206	1.181	1.129	1.150	1.193	1.243	1.291	1.306	1.317
QCIF	*Jurassic Park I*	0.806	0.787	0.749	0.701	0.699	0.675	0.683	0.649	0.622	0.569	0.575
H.–M.Q.	*Jurassic Park I*	1.153	1.176	1.095	0.997	0.983	0.945	0.927	0.968	0.881	0.798	0.849
No R.C.	*Star Wars IV*	0.843	0.838	0.829	0.829	0.835	0.850	0.843	0.849	0.853	0.838	0.867
	Star Wars IV	1.075	1.084	1.024	0.984	0.947	0.888	0.879	0.924	0.918	0.901	0.880
	The Firm	0.878	0.865	0.837	0.814	0.810	0.822	0.812	0.779	0.757	0.724	0.717
	The Firm	1.136	1.169	1.091	1.054	1.084	0.975	1.025	1.063	1.041	0.973	1.011
	Tonight Show w/o Comm	0.847	0.836	0.831	0.843	0.854	0.889	0.851	0.880	0.889	0.855	0.930
	Tonight Show w/o Comm	1.144	1.121	1.077	1.088	1.056	1.060	1.178	1.234	1.226	1.250	1.256
QCIF	*Citizen Kane*	0.877	0.866	0.839	0.813	0.801	0.839	0.828	0.845	0.837	0.859	0.798
M.Q.	*Citizen Kane*	1.087	1.096	1.077	1.003	0.922	0.884	0.897	0.919	0.884	0.862	0.921
No R.C.	*Die Hard I*	0.811	0.785	0.757	0.732	0.720	0.709	0.718	0.727	0.716	0.700	0.650
	Die Hard I	1.100	1.100	1.005	0.946	0.873	0.839	0.923	0.820	0.737	0.766	0.805
	Jurassic Park I	0.799	0.787	0.748	0.710	0.684	0.664	0.664	0.665	0.632	0.589	0.552
	Jurassic Park I	1.124	1.144	1.048	0.929	0.934	0.915	0.923	0.952	0.863	0.801	0.885
	Silence of the Lambs	0.886	0.865	0.856	0.858	0.855	0.820	0.840	0.817	0.782	0.775	0.795
	Silence of the Lambs	1.113	1.144	1.087	1.041	0.983	0.974	0.914	0.899	0.954	0.940	0.955
	Star Wars IV	0.821	0.815	0.804	0.806	0.832	0.849	0.861	0.881	0.874	0.882	0.896
	Star Wars IV	1.036	1.057	0.993	0.943	0.894	0.813	0.787	0.815	0.787	0.809	0.780
	Star Wars V	0.849	0.827	0.820	0.841	0.851	0.857	0.864	0.929	0.923	0.996	0.997
	Star Wars V	1.115	1.090	1.032	0.968	0.919	0.904	0.819	0.815	0.820	0.875	0.832
	The Firm	0.842	0.816	0.788	0.780	0.774	0.812	0.740	0.715	0.750	0.689	0.662
	The Firm	1.093	1.113	1.052	0.992	0.972	0.920	0.963	0.920	0.940	0.890	0.933

Table 10: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	Terminator I	0.906	0.901	0.866	0.834	0.807	0.849	0.824	0.821	0.866	0.809	0.835
	Terminator I	1.066	1.080	1.062	1.033	0.981	1.036	1.004	0.981	1.020	1.002	1.022
	Total Recall	0.811	0.795	0.779	0.766	0.759	0.744	0.740	0.735	0.751	0.732	0.670
	Total Recall	1.105	1.110	1.045	0.961	0.960	0.967	0.963	0.854	0.943	0.915	0.984
	Aladdin	0.864	0.858	0.870	0.877	0.891	0.893	0.816	0.858	0.819	0.784	0.765
	Aladdin	0.967	0.934	0.906	0.868	0.909	0.906	0.934	0.982	0.983	0.987	1.084
	Cinderella	0.778	0.749	0.760	0.761	0.778	0.756	0.736	0.714	0.707	0.697	0.762
	Cinderella	1.027	0.999	0.941	0.908	0.894	0.926	0.935	0.993	0.978	0.989	0.929
	Baseball with Comm	0.775	0.763	0.725	0.704	0.706	0.730	0.738	0.724	0.751	0.775	0.775
	Baseball with Comm	1.069	1.036	1.003	0.918	0.850	0.825	0.806	0.799	0.709	0.730	0.724
	Snowboard with Comm	0.789	0.769	0.747	0.712	0.670	0.624	0.660	0.649	0.636	0.595	0.616
	Snowboard with Comm	1.121	1.061	0.972	0.944	0.828	0.770	0.751	0.741	0.732	0.751	0.801
	Oprah w/o Comm	0.921	0.913	0.903	0.903	0.905	0.979	0.881	0.920	0.969	0.876	0.867
	Oprah w/o Comm	1.077	1.085	1.095	1.081	1.078	1.105	1.162	1.101	1.086	1.025	1.096
	Tonight Show w/o Comm	0.812	0.800	0.798	0.824	0.825	0.845	0.850	0.869	0.854	0.835	0.889
	Tonight Show w/o Comm	1.082	1.018	0.983	0.967	0.931	0.922	1.053	1.024	1.091	1.104	1.173
	Lecture-Gupta	0.955	0.947	0.925	0.910	0.883	0.871	0.842	0.866	0.860	0.837	0.830
	Lecture-Gupta	1.017	1.072	1.133	1.085	0.977	0.995	0.975	0.898	0.888	1.152	0.960
	Lecture-Reisslein	0.945	0.934	0.928	0.917	0.924	0.907	0.942	0.948	0.895	0.933	0.961
	Lecture-Reisslein	1.109	1.103	1.088	1.060	1.033	1.013	1.049	1.045	1.051	1.130	1.086
QCIF M.–L.Q. No R.C.	*Jurassic Park I*	0.797	0.782	0.763	0.714	0.685	0.675	0.698	0.709	0.643	0.629	0.565
	Jurassic Park I	1.115	1.138	1.045	0.919	0.892	0.887	0.893	0.915	0.901	0.779	0.878
	Star Wars IV	0.809	0.803	0.783	0.779	0.814	0.838	0.867	0.865	0.871	0.875	0.888
	Star Wars IV	1.026	1.039	0.982	0.937	0.888	0.831	0.781	0.823	0.779	0.854	0.780
	The Firm	0.830	0.807	0.781	0.764	0.758	0.781	0.722	0.683	0.716	0.676	0.645
	The Firm	1.059	1.087	1.031	0.955	0.932	0.863	0.903	0.842	0.888	0.870	0.918
	Tonight Show w/o Comm	0.807	0.801	0.800	0.825	0.822	0.847	0.841	0.860	0.835	0.823	0.852
	Tonight Show w/o Comm	1.066	1.038	1.011	1.001	0.991	0.988	1.120	1.103	1.129	1.156	1.208
QCIF L.Q. No R.C.	*Citizen Kane*	0.850	0.828	0.795	0.765	0.752	0.770	0.798	0.798	0.786	0.801	0.786
	Citizen Kane	1.056	1.068	1.036	0.939	0.874	0.842	0.828	0.824	0.778	0.779	0.820
	Die Hard I	0.817	0.792	0.763	0.734	0.723	0.724	0.738	0.743	0.725	0.721	0.659
	Die Hard I	1.096	1.094	0.991	0.937	0.899	0.845	0.883	0.833	0.717	0.773	0.802
	Jurassic Park I	0.799	0.790	0.774	0.728	0.695	0.675	0.728	0.726	0.651	0.668	0.598
	Jurassic Park I	1.106	1.139	1.038	0.918	0.871	0.862	0.874	0.883	0.856	0.760	0.827
	Jurassic Park I	0.799	0.790	0.774	0.728	0.695	0.675	0.728	0.726	0.651	0.668	0.598
	Jurassic Park I	1.106	1.139	1.038	0.918	0.871	0.862	0.874	0.883	0.856	0.760	0.827
	Silence of the Lambs	0.851	0.826	0.814	0.825	0.843	0.807	0.803	0.803	0.784	0.782	0.788
	Silence of the Lambs	1.057	1.109	1.056	0.972	0.929	0.918	0.919	0.868	0.945	0.909	0.927
	Star Wars IV	0.792	0.780	0.759	0.751	0.777	0.821	0.839	0.859	0.870	0.845	0.866
	Star Wars IV	1.022	1.032	0.972	0.929	0.872	0.812	0.756	0.790	0.740	0.837	0.746
	Star Wars V	0.820	0.805	0.795	0.819	0.844	0.862	0.892	0.894	0.886	0.960	0.968
	Star Wars V	1.071	1.061	0.978	0.892	0.857	0.820	0.756	0.735	0.753	0.773	0.780
	The Firm	0.823	0.797	0.774	0.749	0.745	0.747	0.707	0.656	0.691	0.671	0.639
	The Firm	1.041	1.062	1.021	0.913	0.904	0.821	0.859	0.780	0.830	0.845	0.855
	Terminator I	0.920	0.903	0.869	0.840	0.811	0.839	0.814	0.822	0.834	0.819	0.793
	Terminator I	1.055	1.071	1.037	1.009	0.984	1.049	0.971	0.992	0.979	0.960	1.041
	Total Recall	0.814	0.802	0.787	0.770	0.762	0.770	0.743	0.749	0.743	0.718	0.664
	Total Recall	1.080	1.091	1.030	0.943	0.943	0.959	0.929	0.878	0.923	0.906	0.952
	Aladdin	0.847	0.842	0.856	0.876	0.897	0.900	0.840	0.860	0.824	0.796	0.779
	Aladdin	0.949	0.917	0.884	0.849	0.878	0.880	0.877	0.914	0.951	0.932	1.018
	Cinderella	0.768	0.760	0.758	0.753	0.756	0.727	0.705	0.700	0.686	0.684	0.729
	Cinderella	1.022	0.984	0.916	0.894	0.851	0.868	0.896	0.980	0.927	0.943	0.948
	Baseball with Comm	0.766	0.744	0.702	0.671	0.648	0.662	0.643	0.609	0.651	0.650	0.684
	Baseball with Comm	1.046	1.015	0.950	0.871	0.822	0.780	0.787	0.802	0.758	0.743	0.715
	Snowboard with Comm	0.793	0.777	0.757	0.718	0.707	0.619	0.678	0.649	0.627	0.631	0.639
	Snowboard with Comm	1.087	1.021	0.941	0.915	0.831	0.746	0.761	0.700	0.676	0.707	0.730
	Oprah w/o Comm	0.888	0.869	0.861	0.854	0.846	0.836	0.782	0.740	0.813	0.801	0.726
	Oprah w/o Comm	1.027	1.038	1.041	1.022	0.990	0.975	1.105	1.027	1.047	0.951	1.012
	Tonight Show w/o Comm	0.813	0.804	0.812	0.825	0.837	0.861	0.850	0.878	0.854	0.851	0.890
	Tonight Show w/o Comm	1.042	1.031	1.002	1.003	0.992	0.997	1.128	1.135	1.137	1.156	1.191
	Lecture-Gupta	0.988	0.991	0.991	0.991	0.989	0.888	0.901	0.872	0.847	0.908	0.912

Table 10: *continued*

Enc. M.	Video	Aggregation level a [frames]										
		12	24	48	96	192	300	396	504	600	696	792
	Lecture-Gupta	0.927	0.962	1.026	0.935	0.852	1.038	1.033	1.083	1.011	1.140	1.052
	Lecture-Reisslein	0.878	0.866	0.877	0.861	0.884	0.889	0.878	0.900	0.853	0.845	0.915
	Lecture-Reisslein	1.023	1.016	1.049	0.983	1.000	1.041	1.039	1.045	1.037	1.208	1.137
QCIF R.C. 64 kbps	*Citizen Kane*	0.893	0.894	0.874	0.854	0.829	0.871	0.825	0.852	0.876	0.840	0.821
	Citizen Kane	1.163	1.165	1.123	1.051	0.976	0.988	0.990	0.957	0.941	0.992	0.985
	Die Hard I	0.806	0.781	0.770	0.746	0.732	0.718	0.695	0.731	0.702	0.707	0.666
	Die Hard I	1.165	1.140	1.036	0.966	0.876	0.837	0.920	0.786	0.742	0.747	0.755
	Jurassic Park I	0.809	0.791	0.763	0.706	0.708	0.676	0.683	0.661	0.634	0.589	0.581
	Jurassic Park I	1.188	1.154	1.067	0.973	0.951	0.915	0.925	0.964	0.887	0.779	0.948
	Silence of the Lambs	0.895	0.886	0.880	0.856	0.850	0.816	0.815	0.800	0.783	0.765	0.722
	Silence of the Lambs	1.124	1.185	1.111	1.047	0.996	1.019	0.918	0.940	0.990	0.973	1.004
	Star Wars IV	0.829	0.830	0.816	0.816	0.840	0.858	0.839	0.850	0.842	0.853	0.856
	Star Wars IV	1.085	1.081	0.994	0.986	0.919	0.878	0.860	0.883	0.865	0.874	0.912
	Star Wars V	0.838	0.830	0.821	0.816	0.809	0.790	0.809	0.805	0.815	0.879	0.851
	Star Wars V	0.834	0.825	0.734	0.612	0.501	0.609	0.441	0.377	0.512	0.485	0.418
	The Firm	0.867	0.841	0.813	0.811	0.795	0.811	0.780	0.745	0.747	0.716	0.689
	The Firm	1.103	1.119	1.065	1.055	1.025	0.962	0.983	0.997	0.993	0.946	0.923
	Terminator I	0.915	0.910	0.898	0.865	0.849	0.864	0.870	0.855	0.875	0.872	0.888
	Terminator I	1.143	1.109	1.076	1.053	1.019	1.036	1.013	0.980	1.040	1.053	1.062
	Total Recall	0.827	0.814	0.794	0.781	0.767	0.749	0.730	0.749	0.762	0.742	0.679
	Total Recall	1.143	1.128	1.046	0.973	0.981	0.973	0.966	0.846	0.924	0.906	1.001
	Aladdin	0.891	0.875	0.885	0.883	0.900	0.897	0.845	0.877	0.849	0.818	0.803
	Aladdin	1.096	1.058	0.992	0.963	1.027	1.001	1.005	1.049	1.022	1.046	1.025
	Cinderella	0.814	0.792	0.800	0.799	0.796	0.786	0.757	0.728	0.728	0.713	0.746
	Cinderella	1.127	1.069	0.980	0.951	0.957	0.934	0.955	0.951	0.993	0.962	0.921
	Baseball with Comm	0.783	0.766	0.741	0.728	0.725	0.763	0.775	0.758	0.795	0.846	0.827
	Baseball with Comm	1.115	1.098	1.041	0.985	0.868	0.853	0.797	0.750	0.770	0.856	0.803
	Snowboard with Comm	0.774	0.752	0.722	0.678	0.645	0.645	0.662	0.684	0.710	0.672	0.729
	Snowboard with Comm	1.169	1.111	0.982	0.963	0.842	0.766	0.758	0.671	0.749	0.703	0.807
	Oprah w/o Comm	0.844	0.826	0.807	0.785	0.766	0.765	0.696	0.691	0.759	0.701	0.668
	Oprah w/o Comm	1.161	1.136	1.067	1.004	1.028	1.020	1.014	0.985	1.051	0.967	1.074
	Tonight Show w/o Comm	0.892	0.886	0.883	0.889	0.863	0.873	0.864	0.895	0.902	0.895	0.940
	Tonight Show w/o Comm	1.115	1.063	1.026	0.964	0.879	0.933	0.963	1.002	1.015	1.031	1.116
	Lecture-Gupta	0.931	0.931	0.924	0.913	0.860	0.868	0.869	0.928	0.894	0.890	0.914
	Lecture-Gupta	1.118	1.188	1.166	1.171	1.054	1.030	1.043	0.935	0.978	1.196	1.070
	Lecture-Reisslein	0.962	0.951	0.936	0.918	0.908	0.873	0.923	0.942	0.850	0.868	0.896
	Lecture-Reisslein	1.206	1.166	1.190	1.155	1.108	1.066	1.086	1.011	1.090	1.027	1.008
QCIF R.C. 128 kbps	*Citizen Kane*	0.870	0.860	0.832	0.818	0.798	0.822	0.797	0.833	0.852	0.884	0.845
	Citizen Kane	1.114	1.136	1.089	0.996	0.918	0.873	0.887	0.844	0.894	0.834	0.845
	Die Hard I	0.800	0.771	0.747	0.719	0.719	0.707	0.708	0.714	0.698	0.697	0.651
	Die Hard I	1.127	1.092	0.985	0.957	0.909	0.828	0.889	0.806	0.697	0.731	0.772
	Jurassic Park I	0.794	0.781	0.747	0.694	0.668	0.618	0.637	0.602	0.579	0.568	0.539
	Jurassic Park I	1.134	1.139	1.057	0.971	0.957	0.919	0.933	0.946	0.869	0.793	0.837
	Silence of the Lambs	0.864	0.862	0.853	0.848	0.832	0.806	0.826	0.820	0.796	0.772	0.776
	Silence of the Lambs	1.161	1.187	1.113	1.044	0.979	0.961	0.901	0.893	0.938	0.938	0.960
	Star Wars IV	0.823	0.815	0.800	0.805	0.838	0.848	0.856	0.859	0.856	0.861	0.885
	Star Wars IV	1.058	1.057	0.987	0.977	0.910	0.839	0.846	0.838	0.809	0.807	0.773
	Star Wars V	0.855	0.816	0.805	0.798	0.797	0.769	0.808	0.815	0.778	0.885	0.863
	Star Wars V	0.810	0.793	0.732	0.564	0.443	0.583	0.422	0.303	0.508	0.473	0.398
	The Firm	0.826	0.805	0.782	0.772	0.769	0.795	0.712	0.681	0.736	0.704	0.644
	The Firm	1.112	1.127	1.073	0.993	0.987	0.903	0.963	0.912	0.961	0.875	0.892
	Terminator I	0.889	0.884	0.866	0.837	0.812	0.853	0.827	0.818	0.881	0.817	0.852
	Terminator I	1.090	1.078	1.057	1.037	0.987	1.001	0.977	0.976	1.012	0.989	1.017
	Total Recall	0.810	0.791	0.778	0.768	0.764	0.766	0.756	0.758	0.758	0.724	0.683
	Total Recall	1.107	1.082	1.021	0.927	0.920	0.945	0.927	0.854	0.897	0.874	0.995
	Aladdin	0.862	0.861	0.870	0.864	0.881	0.874	0.804	0.852	0.807	0.742	0.741
	Aladdin	1.048	0.974	0.932	0.913	0.961	0.939	0.937	0.966	0.970	1.011	1.066
	Cinderella	0.767	0.750	0.753	0.758	0.771	0.758	0.724	0.701	0.711	0.691	0.747
	Cinderella	1.076	1.025	0.933	0.882	0.863	0.882	0.898	0.934	0.957	0.969	0.926
	Baseball with Comm	0.753	0.743	0.718	0.712	0.689	0.700	0.710	0.676	0.700	0.729	0.720
	Baseball with Comm	1.086	1.043	0.991	0.919	0.850	0.808	0.792	0.810	0.773	0.822	0.728

Table 10: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	Snowboard with Comm	0.779	0.752	0.721	0.690	0.673	0.657	0.693	0.697	0.691	0.659	0.688
	Snowboard with Comm	1.150	1.070	0.974	0.948	0.852	0.776	0.750	0.726	0.708	0.691	0.780
	Oprah w/o Comm	0.899	0.891	0.876	0.876	0.885	0.937	0.865	0.885	0.952	0.861	0.855
	Oprah w/o Comm	1.109	1.100	1.092	1.055	1.055	1.026	1.065	1.001	1.008	0.958	1.022
	Tonight Show w/o Comm	0.834	0.823	0.814	0.818	0.809	0.829	0.839	0.881	0.853	0.809	0.861
	Tonight Show w/o Comm	1.104	1.045	1.000	0.962	0.843	0.822	0.893	0.913	0.949	0.968	0.993
	Lecture-Gupta	0.947	0.939	0.923	0.919	0.905	0.872	0.869	0.909	0.872	0.864	0.904
	Lecture-Gupta	1.061	1.119	1.201	1.156	1.076	1.027	1.022	0.947	0.943	1.215	1.029
	Lecture-Reisslein	0.931	0.917	0.917	0.904	0.893	0.893	0.905	0.933	0.872	0.923	0.928
	Lecture-Reisslein	1.172	1.142	1.145	1.103	1.071	1.040	1.030	0.930	1.022	0.973	0.949
QCIF R.C. 256 kbps	*Citizen Kane*	0.867	0.857	0.842	0.824	0.805	0.823	0.805	0.855	0.845	0.875	0.844
	Citizen Kane	1.131	1.131	1.069	0.973	0.893	0.846	0.870	0.862	0.834	0.818	0.810
	Die Hard I	0.794	0.770	0.745	0.711	0.707	0.705	0.696	0.716	0.700	0.709	0.650
	Die Hard I	1.133	1.096	0.993	0.944	0.900	0.836	0.848	0.830	0.689	0.740	0.762
	Jurassic Park I	0.783	0.773	0.743	0.707	0.673	0.631	0.646	0.618	0.612	0.564	0.531
	Jurassic Park I	1.127	1.143	1.047	0.931	0.931	0.900	0.905	0.913	0.867	0.805	0.820
	Silence of the Lambs	0.854	0.849	0.836	0.849	0.838	0.816	0.830	0.827	0.803	0.779	0.794
	Silence of the Lambs	1.186	1.180	1.112	1.035	0.958	0.935	0.881	0.908	0.950	0.927	0.980
	Star Wars IV	0.821	0.814	0.805	0.814	0.863	0.868	0.881	0.892	0.880	0.878	0.903
	Star Wars IV	1.071	1.065	0.987	0.957	0.897	0.838	0.801	0.834	0.760	0.787	0.769
	Star Wars V	0.851	0.804	0.800	0.807	0.823	0.798	0.874	0.859	0.873	0.946	0.981
	Star Wars V	0.794	0.792	0.732	0.551	0.417	0.553	0.383	0.217	0.463	0.400	0.319
	The Firm	0.824	0.803	0.781	0.770	0.769	0.776	0.730	0.671	0.716	0.719	0.680
	The Firm	1.166	1.135	1.056	0.971	0.944	0.864	0.903	0.827	0.892	0.857	0.883
	Terminator I	0.887	0.880	0.854	0.833	0.798	0.837	0.805	0.807	0.843	0.785	0.795
	Terminator I	1.071	1.074	1.055	1.034	0.984	1.014	0.969	0.980	0.999	0.956	1.021
	Total Recall	0.806	0.793	0.779	0.776	0.767	0.779	0.774	0.776	0.775	0.723	0.685
	Total Recall	1.123	1.112	1.031	0.933	0.908	0.939	0.923	0.862	0.877	0.850	0.969
	Aladdin	0.853	0.850	0.856	0.858	0.866	0.868	0.800	0.829	0.789	0.746	0.723
	Aladdin	0.975	0.935	0.911	0.890	0.911	0.898	0.940	0.944	0.967	0.996	1.074
	Cinderella	0.752	0.731	0.736	0.740	0.752	0.747	0.707	0.694	0.696	0.685	0.750
	Cinderella	1.043	0.999	0.923	0.873	0.858	0.888	0.898	0.950	0.945	0.991	0.957
	Baseball with Comm	0.746	0.738	0.706	0.695	0.690	0.642	0.658	0.599	0.607	0.638	0.646
	Baseball with Comm	1.090	1.047	0.993	0.898	0.854	0.787	0.758	0.784	0.714	0.800	0.688
	Snowboard with Comm	0.793	0.770	0.750	0.721	0.688	0.645	0.689	0.678	0.685	0.633	0.680
	Snowboard with Comm	1.128	1.052	0.963	0.941	0.856	0.775	0.767	0.747	0.788	0.766	0.765
	Oprah w/o Comm	0.926	0.919	0.917	0.922	0.929	0.985	0.914	0.936	0.986	0.910	0.895
	Oprah w/o Comm	1.087	1.105	1.110	1.076	1.075	1.087	1.126	1.074	1.069	1.028	1.074
	Tonight Show w/o Comm	0.829	0.817	0.809	0.819	0.821	0.841	0.853	0.904	0.869	0.835	0.863
	Tonight Show w/o Comm	1.088	1.023	0.982	0.924	0.864	0.819	0.886	0.902	0.969	0.976	0.986
	Lecture-Gupta	0.948	0.952	0.930	0.911	0.885	0.847	0.862	0.868	0.803	0.797	0.885
	Lecture-Gupta	0.972	1.032	1.121	1.088	1.031	1.030	1.022	0.985	0.946	1.198	0.960
	Lecture-Reisslein	0.906	0.896	0.899	0.892	0.897	0.899	0.880	0.889	0.864	0.885	0.904
	Lecture-Reisslein	1.102	1.077	1.053	1.007	0.956	0.969	0.966	0.886	0.916	0.986	0.944

Table 11 gives the Hurst parameter estimated using the variance time plot as well as the scaling parameters $\underline{c}_f$ and α (also expressed as $H = (1+\alpha)/2$) estimated from the logscale diagram.

Table 11: Hurst parameters estimated from variance time plot, scaling parameters estimated from logscale diagram.

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
QCIF	*Citizen Kane*	0.854	0.077	0.797	0.898
H.Q.	*Die Hard I*	0.696	0.131	0.61	0.805
No R.C.	*Jurassic Park I*	0.649	0.011	1.092	1.046
	Silence of the Lambs	0.909	0.013	1.014	1.007
	Star Wars IV	0.839	0.148	0.577	0.789
	Star Wars V	0.741	0.011	1.023	1.011
	The Firm	0.8	0.008	1.123	1.062
	Terminator I	0.826	0.027	0.897	0.948
	Total Recall	0.723	0.014	0.973	0.987
	Aladdin	0.877	0.022	0.845	0.922
	Cinderella	0.919	0.065	0.707	0.854
	Baseball with Comm	0.781	0.119	0.615	0.808
	Snowboard with Comm	0.779	2.053	0.218	0.609
	Oprah w/o Comm	0.961	0.006	0.966	0.983
	Tonight Show w/o Comm	0.955	0.074	0.695	0.848
	Lecture-Gupta	0.864	0.001	1.067	1.034
	Lecture-Reisslein	0.954	0	1.282	1.141
QCIF	*Jurassic Park I*	0.604	0.013	1.118	1.059
H.–M.Q.	*Star Wars IV*	0.837	0.655	0.423	0.711
No R.C.	*The Firm*	0.816	0.025	1.014	1.007
	Tonight Show w/o Comm	0.916	0.299173	0.605	0.802
QCIF	*Citizen Kane*	0.832	0.281	0.634	0.817
M.Q.	*Die Hard I*	0.693	0.067	0.846	0.923
No R.C.	*Jurassic Park I*	0.614	0.019	1.079	1.039
	Silence of the Lambs	0.86	0.019	1.02	1.010
	Star Wars IV	0.821	2.331	0.185	0.593
	Star Wars V	0.79	0.134	0.716	0.858
	The Firm	0.79	0.125	0.761	0.880
	Terminator I	0.827	0.038	0.875	0.937
	Total Recall	0.694	0.037	0.934	0.967
	Aladdin	0.865	0.067	0.797	0.898
	Cinderella	0.813	0.267	0.619	0.810
	Baseball with Comm	0.534	0.376	0.577	0.789
	Snowboard with Comm	0.688	0.895	0.45	0.725
	Oprah w/o Comm	0.911	0.01	1.064	1.032
	Tonight Show w/o Comm	0.879	0.436	0.589	0.794
	Lecture-Gupta	0.76	0.156	0.249	0.625
	Lecture-Reisslein	0.926	0.051	0.731	0.865
QCIF	*Jurassic Park I*	0.668	0.027	1	1.000
M.–L.Q.	*Star Wars IV*	0.794	1.519	0.231	0.616
No R.C.	*The Firm*	0.769	0.164	0.684	0.842
	Tonight Show w/o Comm	0.895	0.258	0.623	0.812
QCIF	*Citizen Kane*	0.783	0.213	0.61	0.805
L.Q.	*Die Hard I*	0.697	0.064	0.822	0.911
No R.C.	*Jurassic Park I*	0.705	0.044	0.912	0.956
	Silence of the Lambs	0.818	0.708	0.342	0.671
	Star Wars IV	0.768	1.156	0.357	0.678
	Star Wars V	0.742	0.148	0.668	0.834
	The Firm	0.74	0.234	0.604	0.802
	Terminator I	0.849	0.026	0.912	0.956
	Total Recall	0.717	0.02	0.979	0.989
	Aladdin	0.832	0.04	0.881	0.940

Table 11: *continued*

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
	Cinderella	0.8	0.157	0.663	0.831
	Baseball with Comm	0.509	0.183	0.667	0.833
	Snowboard with Comm	0.684	0.498	0.496	0.748
	Oprah w/o Comm	0.832	0.011	1.056	1.028
	Tonight Show w/o Comm	0.903	0.161	0.65	0.825
	Lecture-Gupta	0.847	0.484	-0.014	0.493
	Lecture-Reisslein	0.928	0.214	0.481	0.740
QCIF R.C. 64 kbps	*Citizen Kane*	0.868	0.21	0.715	0.858
	Die Hard I	0.69	0.079	0.856	0.928
	Jurassic Park I	0.632	0.013	1.158	1.079
	Silence of the Lambs	0.905	0.119	0.578	0.789
	Star Wars IV	0.831	1.68	0.313	0.657
	Star Wars V	0.716	0.037	0.948	0.974
	The Firm	0.822	0.021	1.067	1.033
	Terminator I	0.826	0.025	0.972	0.986
	Total Recall	0.719	0.026	1.013	1.007
	Aladdin	0.881	0.03	0.921	0.961
	Cinderella	0.793	0.11	0.777	0.889
	Baseball with Comm	0.652	0.549	0.545	0.773
	Snowboard with Comm	0.62	2.392	0.236	0.618
	Oprah w/o Comm	0.799	0.024	0.981	0.990
	Tonight Show w/o Comm	0.88	0.129	0.754	0.877
	Lecture-Gupta	0.833	0.013	0.976	0.988
	Lecture-Reisslein	0.916	0.004	1.122	1.061
QCIF R.C. 128 kbps	*Citizen Kane*	0.846	6.523	0.168	0.584
	Die Hard I	0.669	0.14	0.719	0.859
	Jurassic Park I	0.572	5.507	0.27	0.635
	Silence of the Lambs	0.861	4.981	0.099	0.549
	Star Wars IV	0.834	0.916	0.372	0.686
	Star Wars V	0.748	0.115	0.765	0.883
	The Firm	0.784	0.083	0.868	0.934
	Terminator I	0.818	0.068	0.82	0.910
	Total Recall	0.688	0.042	0.92	0.960
	Aladdin	0.871	0.065	0.838	0.919
	Cinderella	0.806	0.179	0.657	0.828
	Baseball with Comm	0.499	0.485	0.538	0.769
	Snowboard with Comm	0.671	1.499	0.3	0.650
	Oprah w/o Comm	0.884	0.023	0.979	0.990
	Tonight Show w/o Comm	0.861	0	1.481	1.240
	Lecture-Gupta	0.777	0.005	1.091	1.046
	Lecture-Reisslein	0.917	0.001	1.369	1.184
QCIF R.C. 256 kbps	*Citizen Kane*	0.846	0.244	0.645	0.823
	Die Hard I	0.667	0.107	0.739	0.869
	Jurassic Park I	0.605	0.106	0.499	0.749
	Silence of the Lambs	0.832	0	1.638	1.319
	Star Wars IV	0.853	0.027	0.947	0.973
	Star Wars V	0.759	0.272	0.607	0.804
	The Firm	0.751	0.172	0.709	0.855
	Terminator I	0.82	0.024	0.925	0.962
	Total Recall	0.701	0.046	0.885	0.942
	Aladdin	0.865	0.039	0.91	0.955
	Cinderella	0.812	0.162	0.649	0.825
	Baseball with Comm	0.461	0.333	0.577	0.788
	Snowboard with Comm	0.709	0.736	0.471	0.735
	Oprah w/o Comm	0.918	0.011	1.046	1.023
	Tonight Show w/o Comm	0.869	0.755	0.515	0.757
	Lecture-Gupta	0.736	0.017	0.648	0.824
	Lecture-Reisslein	0.893	0.004	1.154	1.077

Table 12 gives the scaling parameters α_q for the orders $q = 0.5$, 1, 1.5, 2, 2.5, 3, 3.5, and 4.

Table 12: Scaling parameters estimated from multiscale diagram.

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
QCIF	*Citizen Kane*	0.514	0.973	1.380	1.744	2.076	2.381	2.666	2.935
H.Q.	*Die Hard I*	0.417	0.826	1.220	1.595	1.952	2.289	2.609	2.913
No R.C.	*Jurassic Park I*	0.551	1.068	1.570	2.075	2.584	3.089	3.589	4.084
	Silence of the Lambs	0.532	1.034	1.524	2.010	2.492	2.970	3.444	3.914
	Star Wars IV	0.429	0.823	1.193	1.546	1.883	2.208	2.523	2.830
	Star Wars V	0.535	1.049	1.542	2.015	2.470	2.910	3.336	3.752
	The Firm	0.550	1.090	1.618	2.126	2.612	3.074	3.518	3.951
	Terminator I	0.511	0.989	1.445	1.885	2.313	2.731	3.141	3.547
	Total Recall	0.517	1.008	1.479	1.931	2.364	2.780	3.179	3.564
	Aladdin	0.481	0.945	1.395	1.834	2.266	2.693	3.116	3.535
	Cinderella	0.482	0.926	1.335	1.711	2.055	2.373	2.673	2.963
	Baseball with Comm	0.419	0.812	1.191	1.559	1.919	2.273	2.624	2.972
	Snowboard with Comm	0.297	0.599	0.907	1.215	1.519	1.816	2.105	2.387
	Oprah w/o Comm	0.489	0.964	1.442	1.927	2.413	2.894	3.363	3.818
	Tonight Show w/o Comm	0.538	1.042	1.522	1.977	2.406	2.814	3.205	3.583
	Lecture-Gupta	0.659	1.178	1.607	1.990	2.350	2.698	3.040	3.379
	Lecture-Reisslein	0.678	1.280	1.806	2.252	2.650	3.022	3.382	3.735
QCIF	*Jurassic Park I*	0.545	1.062	1.573	2.091	2.607	3.110	3.595	4.064
H.–M.Q.	*Star Wars IV*	0.379	0.731	1.065	1.385	1.694	1.994	2.286	2.571
No R.C.	*The Firm*	0.541	1.061	1.557	2.025	2.463	2.874	3.265	3.644
	Tonight Show w/o Comm	0.528	1.026	1.488	1.913	2.305	2.672	3.022	3.359
QCIF	*Citizen Kane*	0.478	0.889	1.251	1.571	1.850	2.093	2.309	2.504
M.Q.	*Die Hard I*	0.476	0.934	1.378	1.818	2.257	2.697	3.138	3.576
No R.C.	*Jurassic Park I*	0.508	1.011	1.525	2.049	2.562	3.056	3.530	3.988
	Silence of the Lambs	0.540	1.052	1.551	2.029	2.480	2.909	3.326	3.736
	Star Wars IV	0.333	0.628	0.889	1.123	1.340	1.550	1.756	1.960
	Star Wars V	0.455	0.891	1.302	1.683	2.033	2.354	2.647	2.917
	The Firm	0.497	0.954	1.371	1.747	2.086	2.393	2.674	2.937
	Terminator I	0.516	0.995	1.447	1.878	2.294	2.697	3.089	3.473
	Total Recall	0.508	0.995	1.464	1.922	2.370	2.810	3.242	3.668
	Aladdin	0.484	0.946	1.390	1.816	2.225	2.622	3.007	3.384
	Cinderella	0.474	0.914	1.306	1.648	1.948	2.222	2.483	2.739
	Baseball with Comm	0.404	0.793	1.171	1.543	1.908	2.263	2.608	2.938
	Snowboard with Comm	0.370	0.739	1.103	1.463	1.818	2.168	2.510	2.846
	Oprah w/o Comm	0.558	1.082	1.578	2.048	2.493	2.919	3.332	3.736
	Tonight Show w/o Comm	0.531	1.024	1.471	1.875	2.245	2.592	2.923	3.244
	Lecture-Gupta	0.234	0.539	0.908	1.314	1.769	2.212	2.650	3.079
	Lecture-Reisslein	0.557	1.036	1.444	1.785	2.070	2.316	2.538	2.746
QCIF	*Jurassic Park I*	0.497	0.977	1.470	1.979	2.489	2.989	3.471	3.937
M.–L.Q.	*Star Wars IV*	0.299	0.613	0.913	1.193	1.459	1.716	1.967	2.212
No R.C.	*The Firm*	0.479	0.918	1.315	1.675	2.005	2.310	2.594	2.862
	Tonight Show w.o Comm	0.550	1.056	1.521	1.953	2.356	2.738	3.105	3.462
QCIF	*Citizen Kane*	0.468	0.864	1.216	1.538	1.841	2.130	2.408	2.675
L.Q.	*Die Hard I*	0.470	0.920	1.359	1.789	2.215	2.637	3.059	3.480
No R.C.	*Jurassic Park I*	0.476	0.939	1.409	1.891	2.377	2.857	3.323	3.776
	Silence of the Lambs	0.422	0.764	1.042	1.251	1.389	1.466	1.499	1.504
	Star Wars IV	0.329	0.671	1.015	1.359	1.701	2.040	2.374	2.701
	Star Wars V	0.429	0.844	1.249	1.640	2.018	2.381	2.733	3.074
	The Firm	0.461	0.880	1.258	1.604	1.924	2.226	2.516	2.795
	Terminator I	0.506	0.990	1.452	1.897	2.323	2.746	3.151	3.546
	Total Recall	0.494	0.990	1.485	1.973	2.457	2.935	3.409	3.879
	Aladdin	0.481	0.949	1.402	1.835	2.243	2.632	3.002	3.354
	Cinderella	0.475	0.918	1.323	1.685	2.010	2.310	2.597	2.879
	Baseball with Comm	0.418	0.831	1.239	1.642	2.033	2.414	2.783	3.140
	Snowboard with Comm	0.384	0.756	1.121	1.482	1.835	2.180	2.516	2.844
	Oprah w/o Comm	0.531	1.042	1.537	2.018	2.491	2.954	3.405	3.860

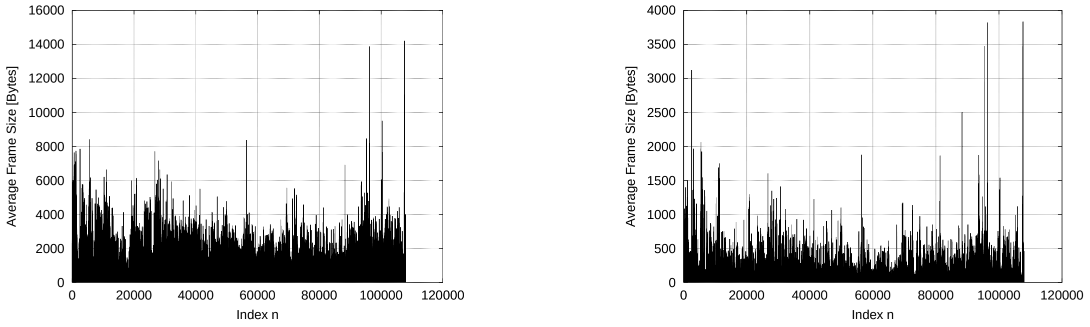
Table 12: *continued*

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
	Tonight Show w/o Comm	0.527	1.025	1.489	1.923	2.330	2.717	3.090	3.452
	Lecture-Gupta	0.258	0.570	0.940	1.320	1.702	2.084	2.458	2.822
	Lecture-Reisslein	0.471	0.869	1.194	1.444	1.625	1.754	1.850	1.929
QCIF	*Citizen Kane*	0.500	0.933	1.313	1.658	1.983	2.295	2.600	2.899
R.C.	*Die Hard I*	0.476	0.934	1.385	1.839	2.297	2.759	3.228	3.706
64 kbps	*Jurassic Park I*	0.551	1.076	1.606	2.150	2.700	3.247	3.780	4.300
	Silence of the Lambs	0.468	0.867	1.178	1.410	1.580	1.702	1.792	1.862
	Star Wars IV	0.354	0.682	0.984	1.270	1.547	1.818	2.085	2.347
	Star Wars V	0.479	0.945	1.408	1.867	2.318	2.755	3.179	3.589
	The Firm	0.551	1.078	1.580	2.062	2.524	2.971	3.406	3.831
	Terminator I	0.520	1.017	1.494	1.960	2.415	2.862	3.301	3.734
	Total Recall	0.519	1.022	1.511	1.988	2.455	2.913	3.366	3.813
	Aladdin	0.501	0.989	1.464	1.925	2.375	2.813	3.243	3.666
	Cinderella	0.478	0.943	1.383	1.790	2.162	2.503	2.820	3.122
	Baseball with Comm	0.409	0.786	1.151	1.512	1.871	2.228	2.584	2.935
	Snowboard with Comm	0.276	0.589	0.900	1.196	1.472	1.726	1.960	2.175
	Oprah w/o Comm	0.535	1.034	1.510	1.968	2.411	2.840	3.258	3.666
	Tonight Show w/o Comm	0.527	1.020	1.481	1.912	2.319	2.710	3.089	3.460
	Lecture-Gupta	0.579	1.116	1.596	2.021	2.403	2.757	3.095	3.425
	Lecture-Reisslein	0.642	1.190	1.676	2.125	2.552	2.967	3.373	3.773
QCIF	*Citizen Kane*	0.422	0.731	0.955	1.124	1.267	1.399	1.527	1.655
R.C.	*Die Hard I*	0.464	0.888	1.292	1.684	2.070	2.451	2.827	3.196
128 kbps	*Jurassic Park I*	0.636	1.125	1.404	1.499	1.505	1.482	1.453	1.428
	Silence of the Lambs	0.443	0.741	0.890	0.885	0.752	0.537	0.281	0.007
	Star Wars IV	0.370	0.712	1.034	1.340	1.632	1.908	2.169	2.416
	Star Wars V	0.423	0.836	1.259	1.688	2.112	2.526	2.927	3.316
	The Firm	0.534	1.030	1.491	1.918	2.310	2.675	3.024	3.363
	Terminator I	0.505	0.975	1.416	1.835	2.238	2.629	3.012	3.387
	Total Recall	0.504	0.984	1.447	1.897	2.334	2.761	3.183	3.598
	Aladdin	0.487	0.952	1.402	1.841	2.272	2.696	3.115	3.530
	Cinderella	0.479	0.922	1.327	1.691	2.014	2.305	2.576	2.836
	Baseball with Comm	0.403	0.775	1.147	1.521	1.893	2.255	2.603	2.934
	Snowboard with Comm	0.336	0.656	0.975	1.288	1.591	1.882	2.161	2.428
	Oprah w/o Comm	0.556	1.065	1.534	1.972	2.383	2.772	3.148	3.514
	Tonight Show w/o Comm	0.630	1.291	1.940	2.530	3.057	3.529	3.961	4.367
	Lecture-Gupta	0.482	1.028	1.598	2.144	2.661	3.154	3.629	4.095
	Lecture-Reisslein	0.626	1.257	1.881	2.492	3.087	3.669	4.240	4.852
QCIF	*Citizen Kane*	0.497	0.921	1.285	1.596	1.866	2.101	2.311	2.504
R.C.	*Die Hard I*	0.451	0.878	1.296	1.706	2.110	2.509	2.903	3.293
256 kbps	*Jurassic Park I*	0.506	1.008	1.502	1.998	2.443	2.926	3.361	3.780
	Silence of the Lambs	0.610	1.166	1.702	2.233	2.766	3.299	3.830	4.357
	Star Wars IV	0.544	1.053	1.530	1.967	2.360	2.667	2.996	3.313
	Star Wars V	0.397	0.786	1.159	1.517	1.864	2.197	2.517	2.824
	The Firm	0.496	0.952	1.355	1.702	1.999	2.255	2.483	2.692
	Terminator I	0.504	0.979	1.434	1.874	2.303	2.723	3.134	3.538
	Total Recall	0.497	0.971	1.429	1.874	2.309	2.733	3.148	3.557
	Aladdin	0.501	0.977	1.436	1.881	2.316	2.741	3.157	3.564
	Cinderella	0.480	0.920	1.330	1.710	2.056	2.372	2.665	2.945
	Baseball with Comm	0.384	0.772	1.166	1.561	1.951	2.330	2.694	3.039
	Snowboard with Comm	0.372	0.742	1.114	1.486	1.856	2.221	2.581	2.933
	Oprah w/o Comm	0.564	1.086	1.574	2.032	2.464	2.878	3.278	3.671
	Tonight Show w/o Comm	0.519	0.979	1.379	1.724	2.030	2.313	2.582	2.843
	Lecture-Gupta	0.555	0.977	1.296	1.553	1.780	1.994	2.204	2.411
	Lecture-Reisslein	0.572	1.141	1.708	2.273	2.828	3.373	3.904	4.422

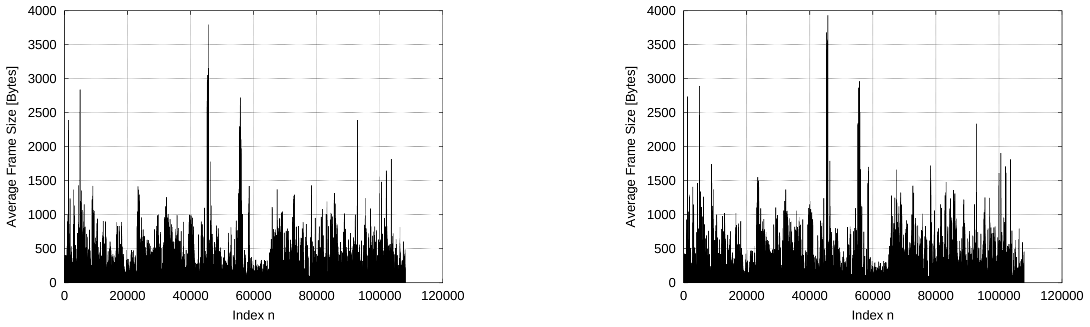
Figures 20, 21, and 22 give the variance-time plots, the pox plots of R/S (for $a = 12$), and the periodogram (for $a = 12$). Figure 23 gives the logscale diagrams. Figures 24 and 25 give the multiscale diagrams and the linear multiscale diagrams.

In summary, we observe from the scaling analysis that the enhancement layers of the encodings without rate control exhibit long range dependence and have scaling properties that are very similar to the corresponding single layer encodings without rate control. *Die Hard I* and *Jurassic Park I* again have the smallest degree of long range dependence. Again, there appears to be no clear trend in the Hurst parameter estimates for the different quality levels of a given video. In contrast to earlier results, the enhancement layers of the encodings with rate control now exhibit long range dependence, which is due to the enhancement layers being encoded with fixed quantization parameters, whereas the corresponding base layers are rate-controlled.

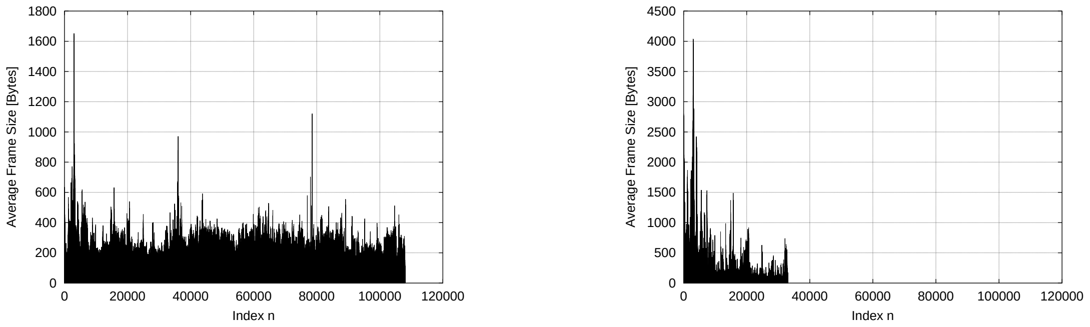
Notice from Figure 25d that the confidence intervals of $h_{0.5}$ and h_4 are separated by approximately 0.1, which gives some indication of multiscaling properties. Interestingly, this particular video traffic stream considered in Figure 25d is the only stream in our library that gives this indication of multiscaling.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



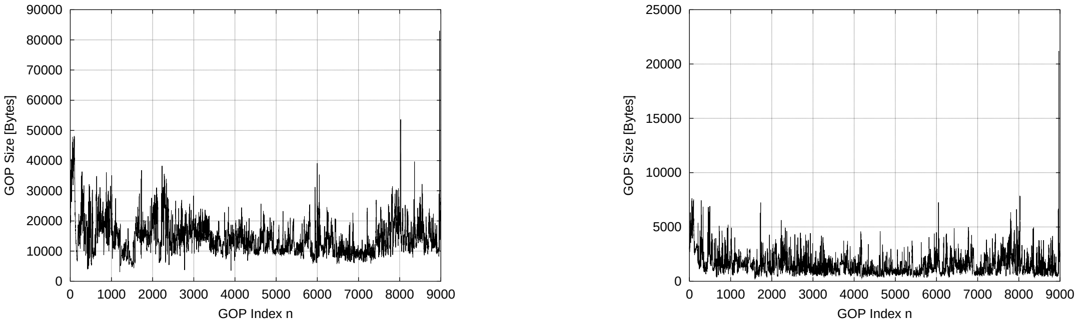
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



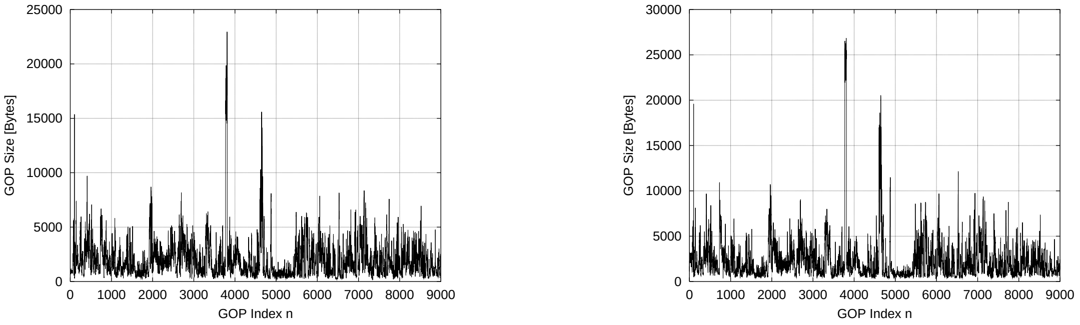
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

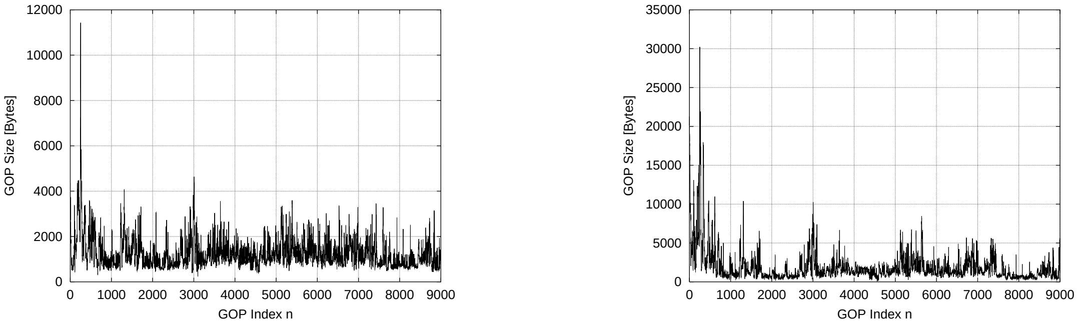
Figure 14: Enhancement layer frame size X_n^e as a function of the frame index n for temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



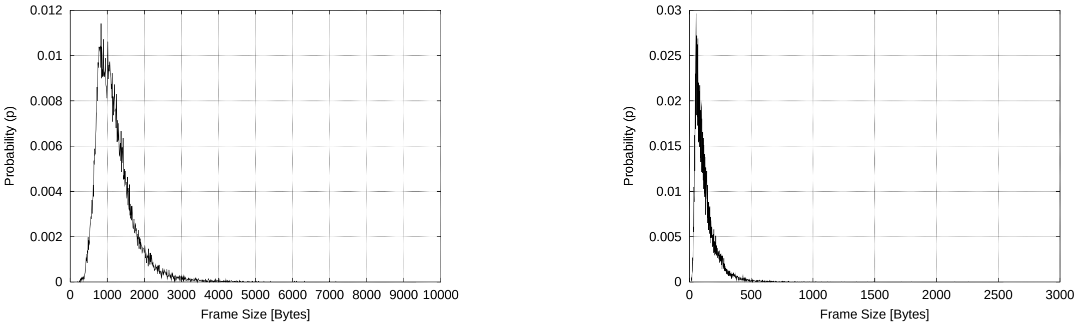
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

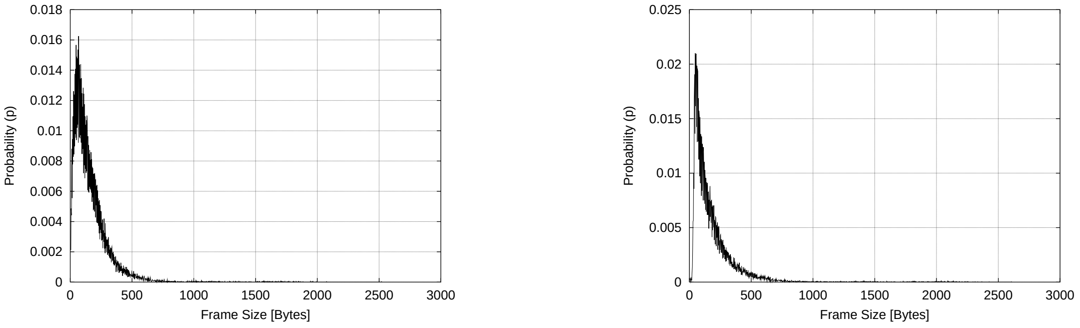
Encoding without rate control Encoding with rate control

Figure 15: GoP size Y_m^e as a function of the index m for temporal scalable QCIF video.



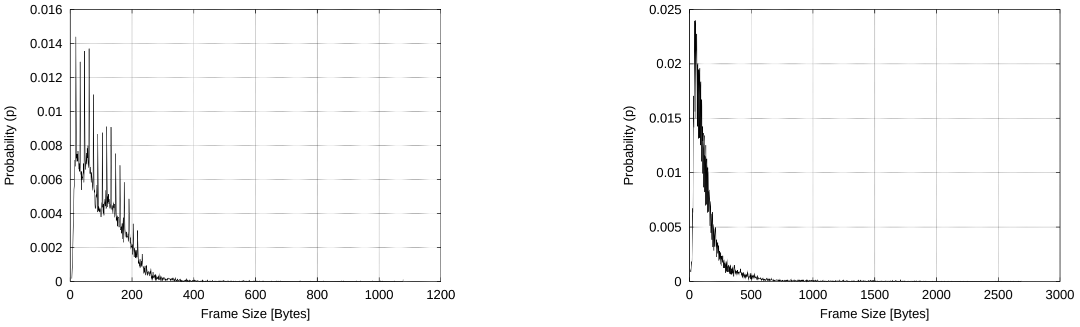
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



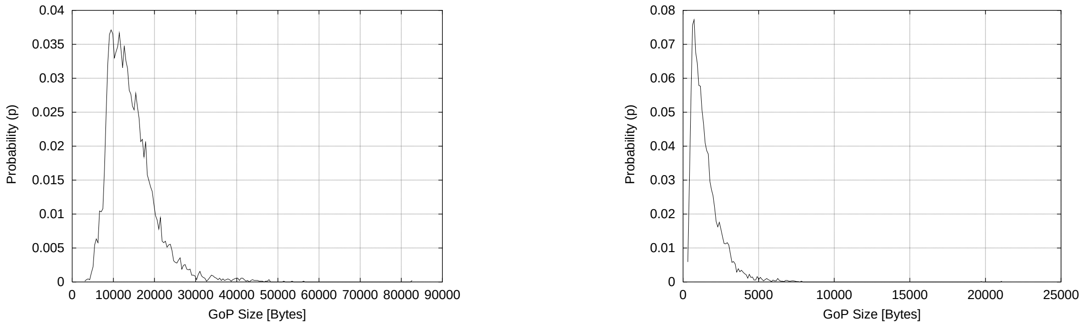
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control

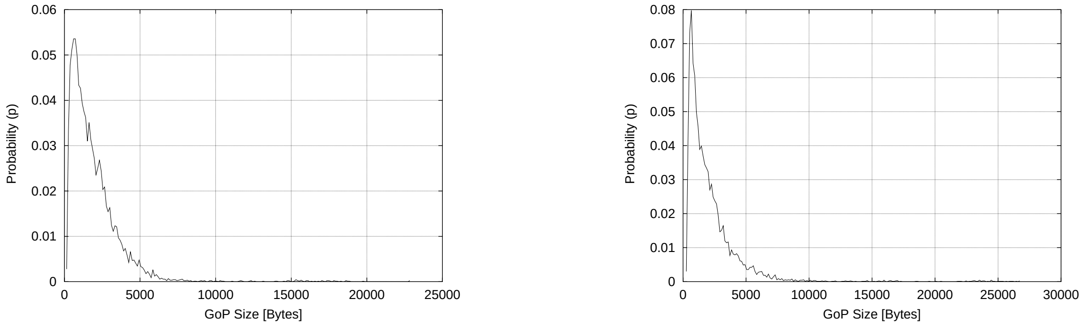
Encoding with rate control

Figure 16: Frame size histograms for the enhancement layer of temporal scalable QCIF video.



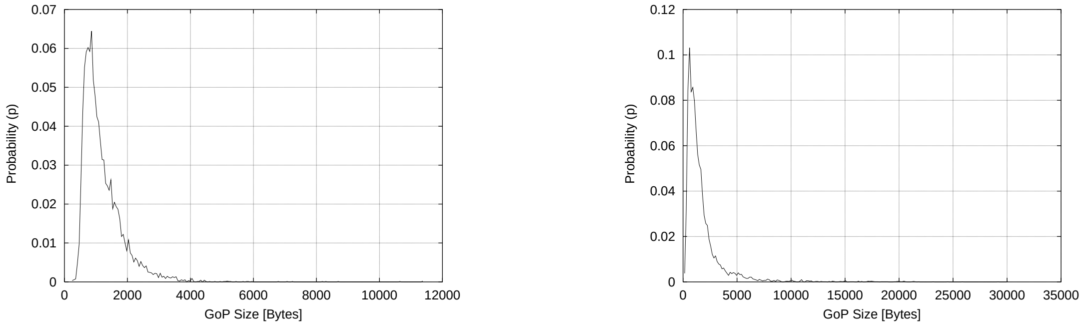
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



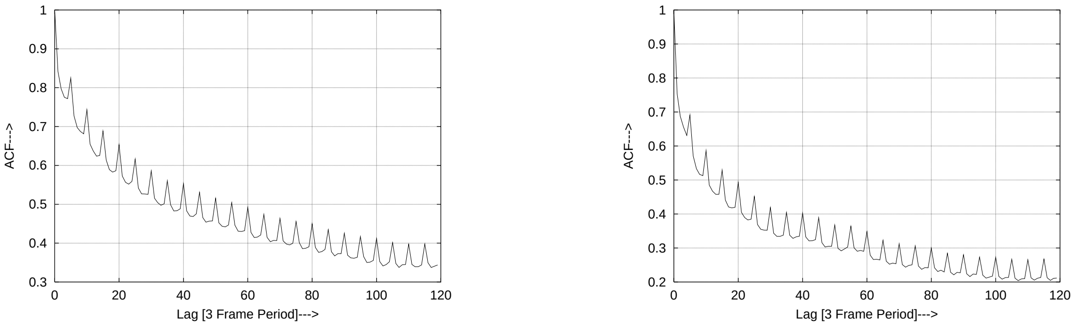
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

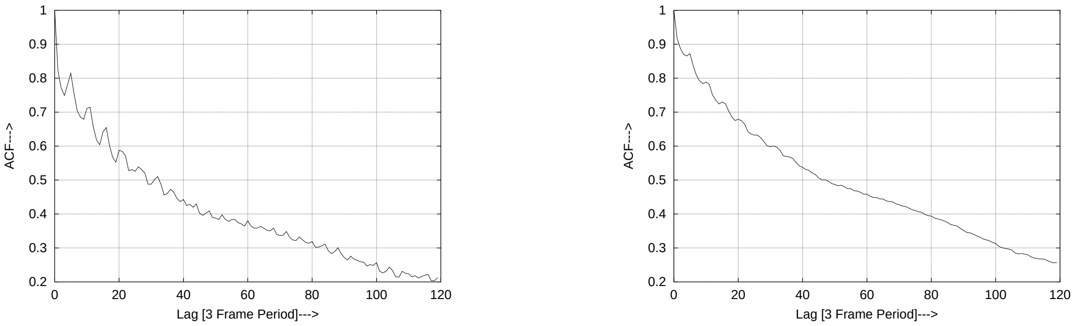
Encoding without rate control

Encoding with rate control

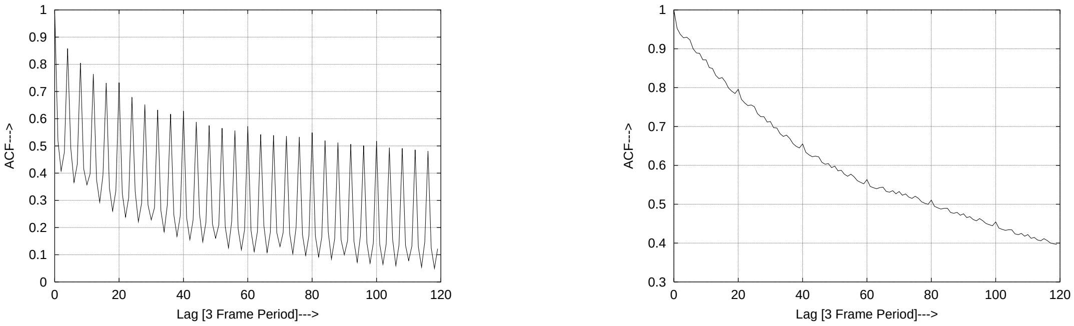
Figure 17: GoP size histograms for the enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



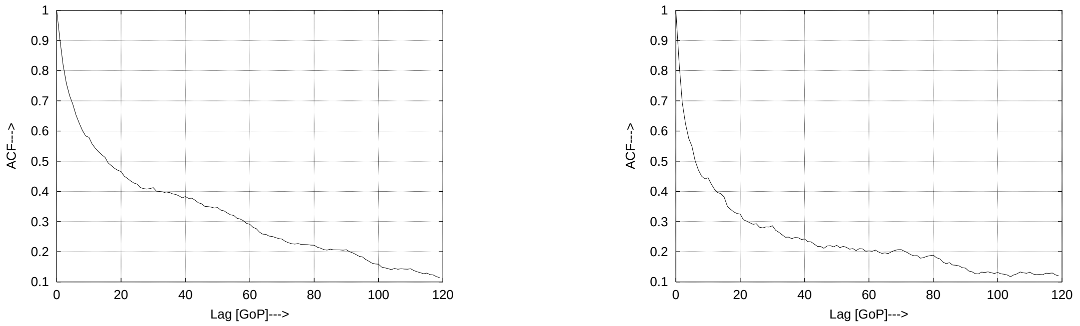
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

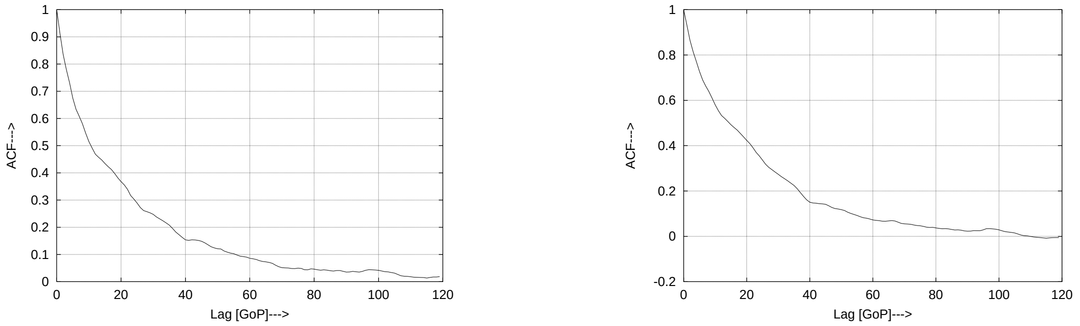
Encoding without rate control Encoding with rate control

Figure 18: Frame size autocorrelations for the enhancement layer of temporal scalable QCIF video.



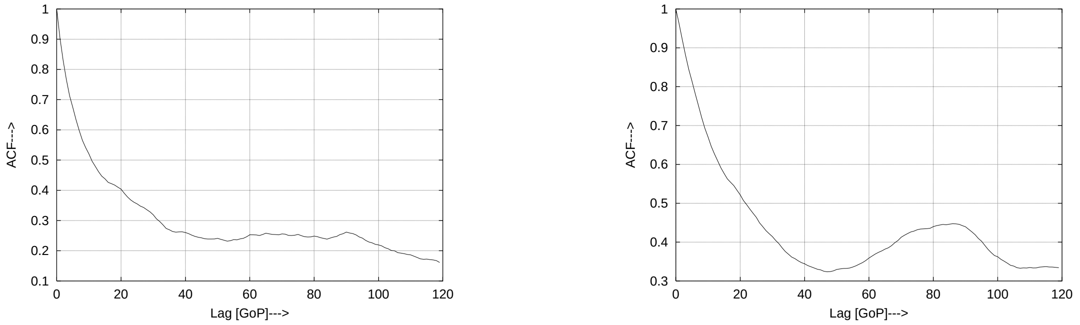
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



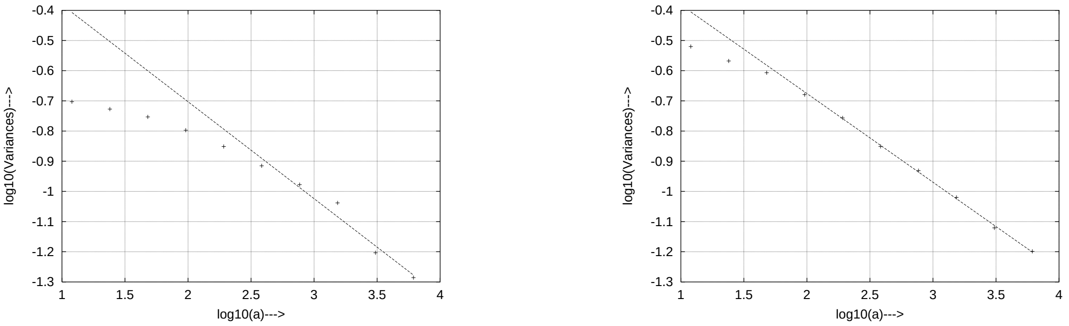
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

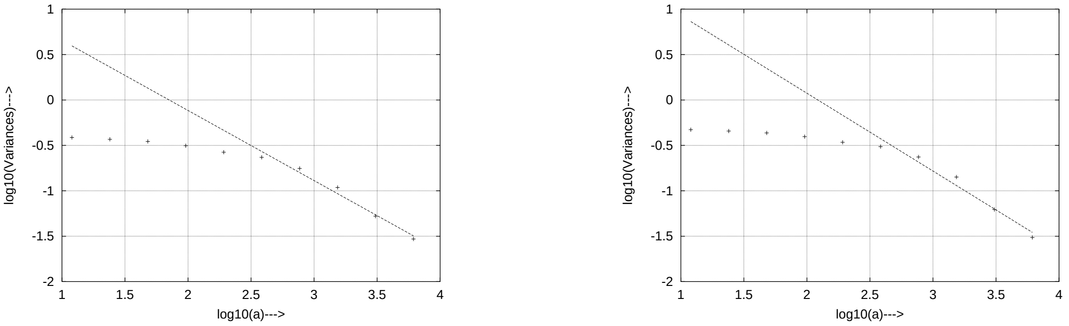
Encoding without rate control

Encoding with rate control

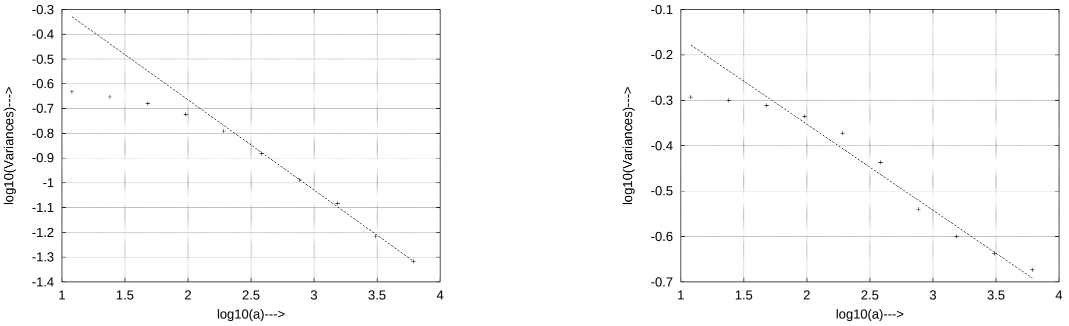
Figure 19: GoP size correlations for the enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



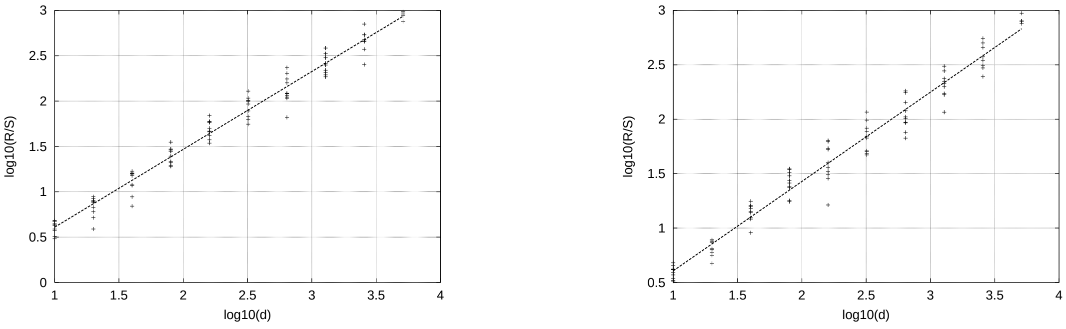
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



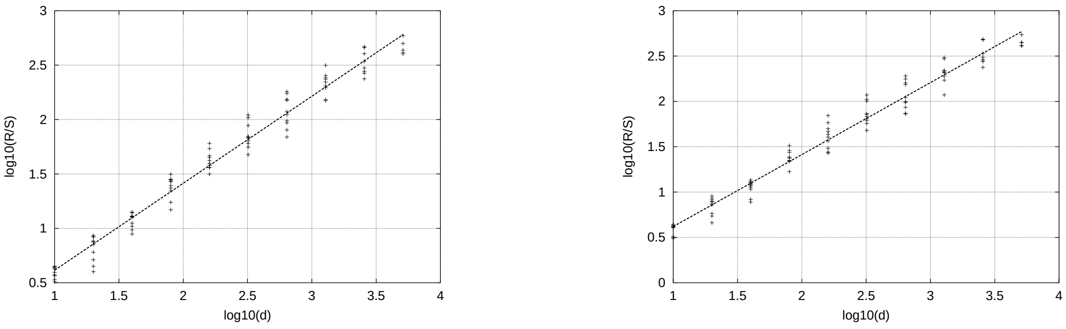
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

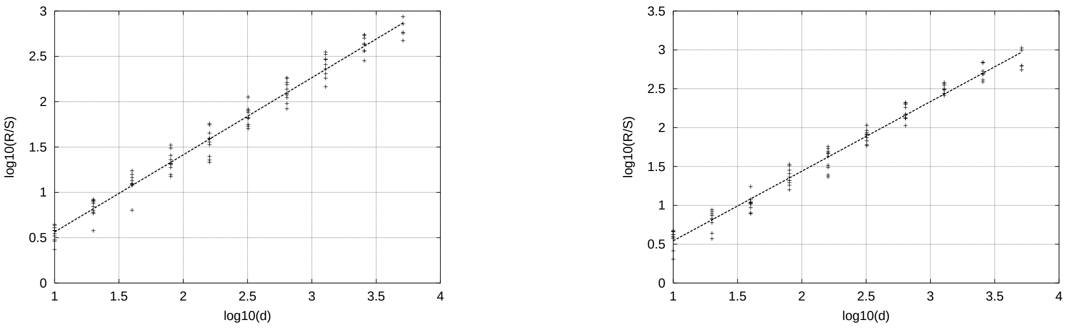
Figure 20: Variance time plots for enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



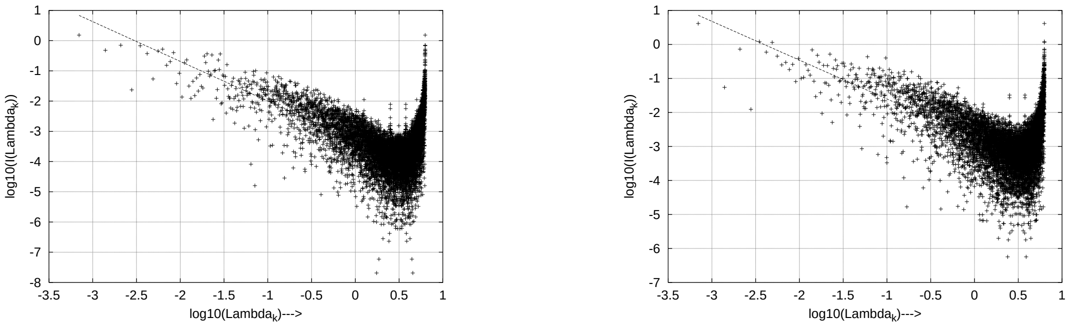
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



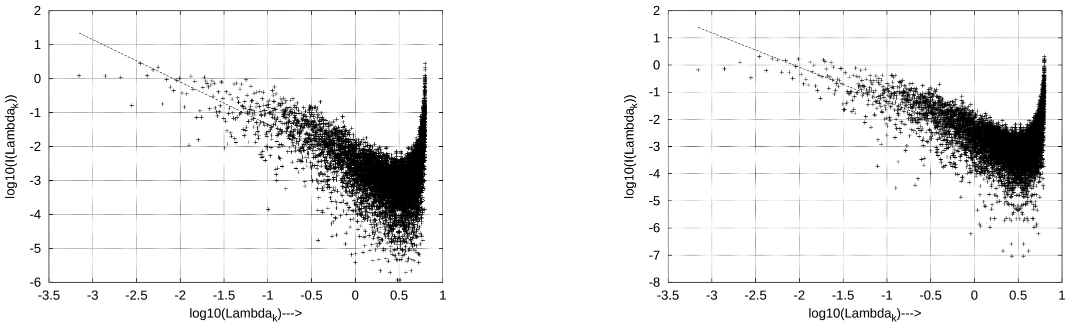
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

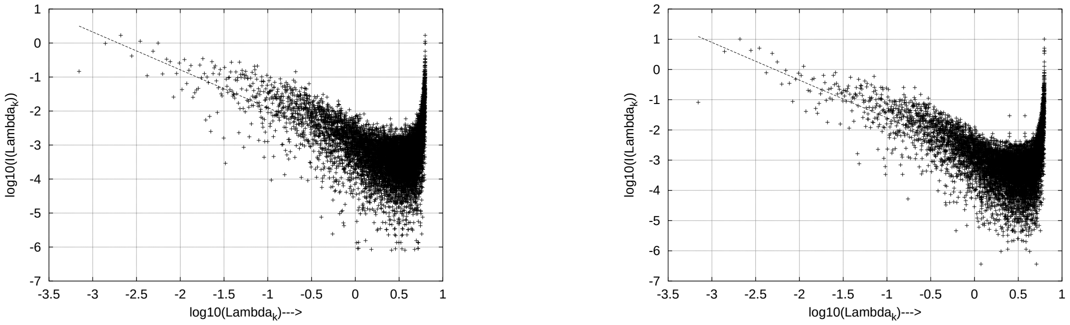
Figure 21: Pox plots of R/S for aggregation level $a = 12$ for enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



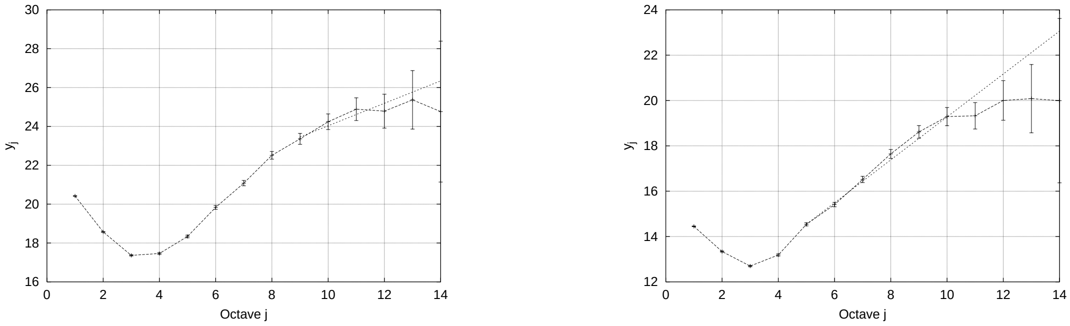
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

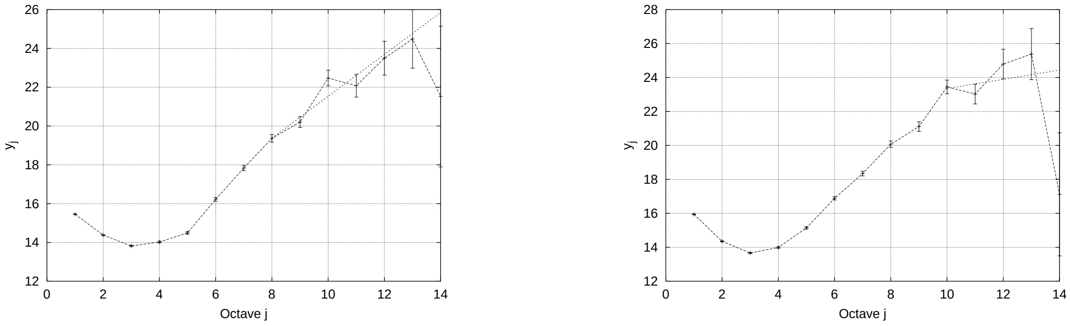
Encoding without rate control Encoding with rate control

Figure 22: Periodograms for aggregation level $a = 12$ for enhancement layer of temporal scalable QCIF video.



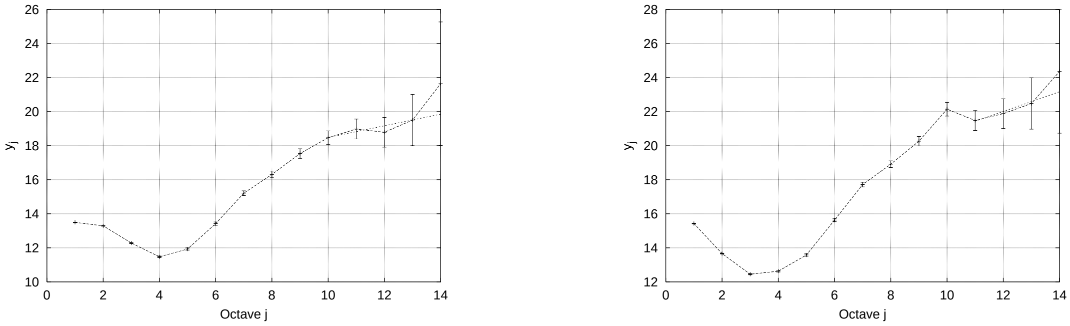
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



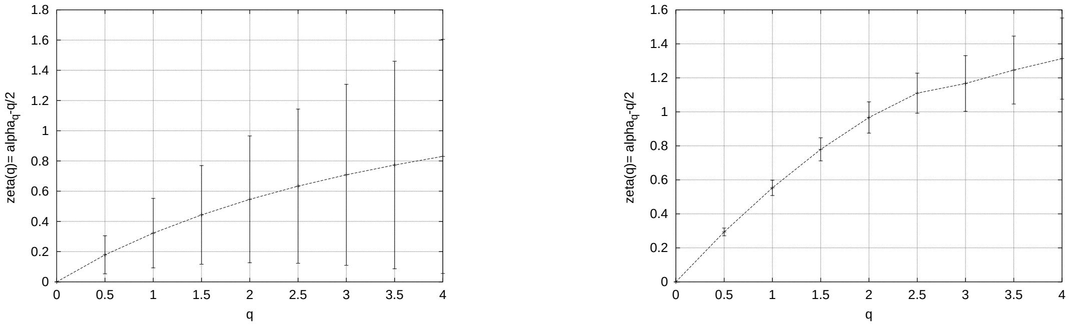
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

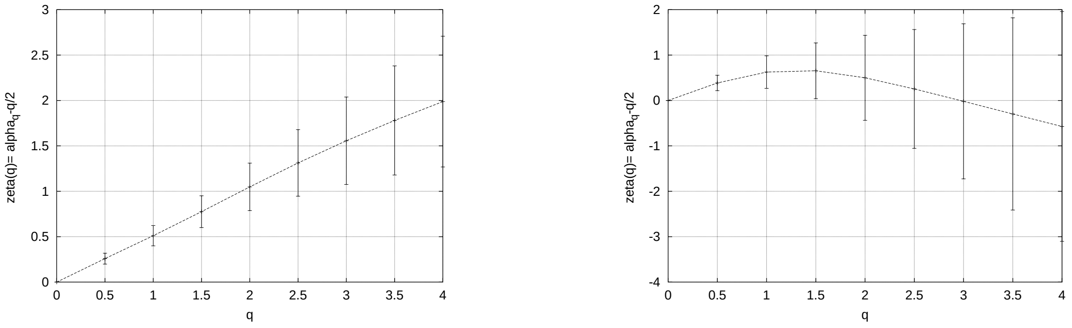
Encoding without rate control

Encoding with rate control

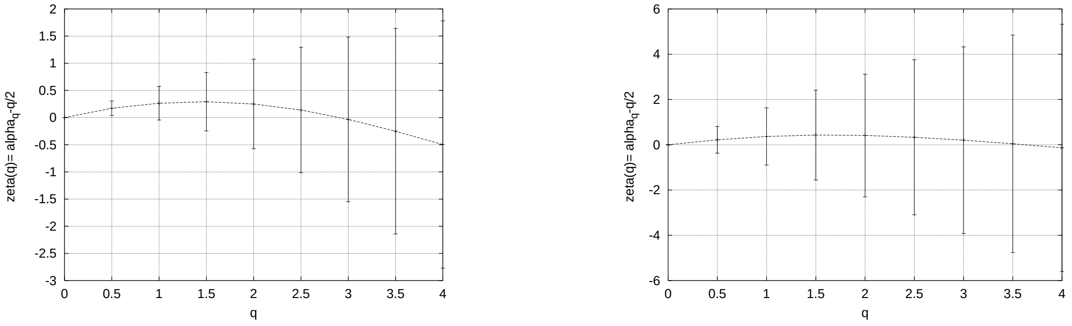
Figure 23: Logscale diagrams for enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



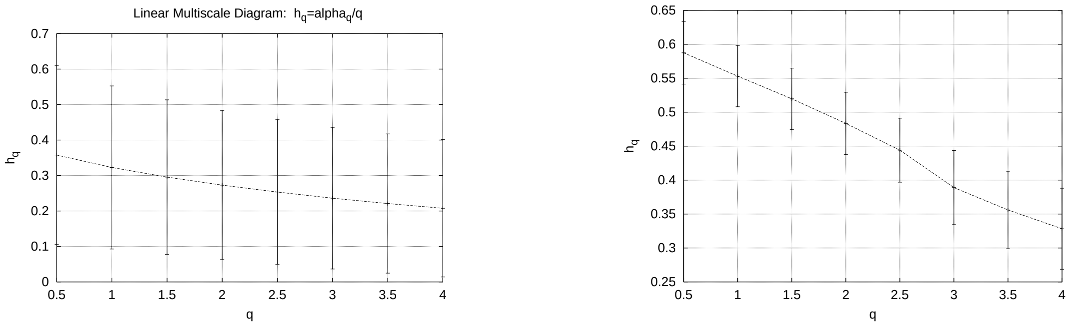
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



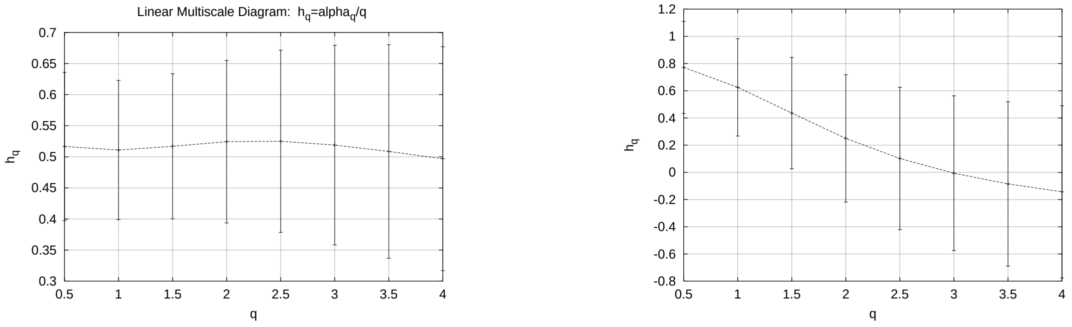
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

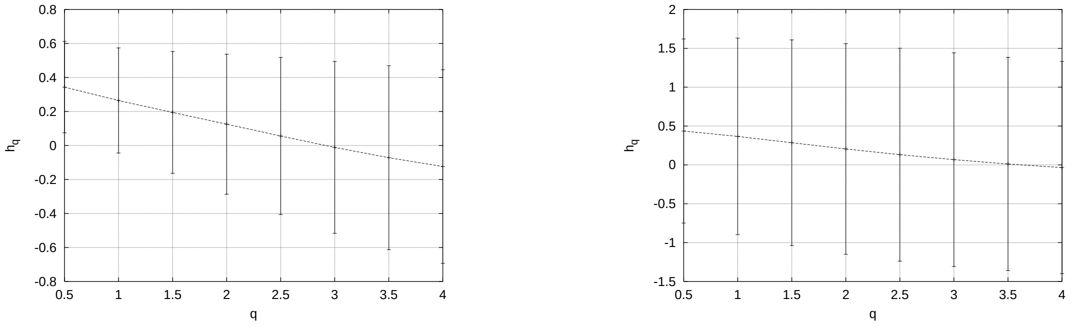
Figure 24: Multiscale diagrams for enhancement layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

Figure 25: Linear multiscale diagrams for enhancement layer of temporal scalable QCIF video.

2.3 Aggregated Traffic and Correlation between Base and Enhancement Layer Traffic

In this section we investigate the aggregate (base + enhancement layer) traffic and the correlation between the base layer and the enhancement layer traffic of temporal scalable encoded video. In this investigation we consider the smoothed base layer trace $X_n^{b(3)}$, $n = 0, \ldots, N/3-1$, and the 3-frame smoothed enhancement layer trace $X_n^{e(3)}$, $n = 0, \ldots, N/3-1$. We estimate the covariance between base layer and enhancement layer at the 3-frame aggregation level as

$$S_{be}^{(3)} = \frac{1}{N/3-1} \sum_{n=0}^{N/3-1} (X_n^{b(3)} - \bar{X}^b)(X_n^{e(3)} - \bar{X}^e), \tag{1}$$

and the base–enhancement layer correlation coefficient as

$$\rho_{be}^{(3)} = \frac{S_{be}^{(3)}}{S_{X^{(3)}}^b \cdot S_{X^{(3)}}^e}. \tag{2}$$

Similarly, we estimate the covariance between base layer and enhancement layer at the GoP level as

$$S_{be}^{(G)} = \frac{1}{N/G-1} \sum_{m=0}^{N/G-1} (Y_m^b - \bar{Y}^b)(Y_m^e - \bar{Y}^e), \tag{3}$$

and the corresponding correlation coefficient as

$$\rho_{be}^{(G)} = \frac{S_{be}^{(G)}}{S_Y^b \cdot S_Y^e}. \tag{4}$$

We also investigate the characteristics of the aggregate traffic at the frame time scale $X_n = X_n^b + X_n^e$, $n = 0, \ldots, N-1$, and the GoP time scale $Y_m = Y_m^b + Y_m^e$, $m = 0, \ldots, N/G-1$. The compression ratios, mean frame sizes ($\bar{X}$), the coefficients of variation (CoV_X), the peak-to-mean ratios ($X_{\max}/\bar{X}$), along with the bit rates and the base-enhancement layer correlation coefficients ($\rho_{be}^{(3)}$) are reported in Table 13. Table 14 gives the mean GoP sizes ($\bar{Y}$), the coefficients of variation (CoV_Y), the peak-to-mean ratios ($Y_{\max}/\bar{Y}$), along with the peak bit rates ($Y_{\max}/(GT)$) and the GoP level base-enhancement layer correlation coefficients (ρ_{be}^G).

For the encodings without rate control we observe that the frame level and GoP level statistics are approximately equal to the corresponding statistics of the single layer encodings studied in Part 2. For the temporal scalable encodings with rate control, on the other hand, the rate-controlled base layer and the open-loop encoded enhancement layer are aggregated. For the 64 kbps base layer encodings, the resulting aggregated traffic stream is at the frame level less variable than the 64 kbps single layer encodings (although this may be due to the failure of the TM5 rate control to meet this target bit rate for the single layer) but significantly more variable than the medium and low quality level single layer encodings without rate control. For the 128 kbps and 256 kbps base layer encodings, the variability of the aggregate frame level traffic is roughly comparable to the variability of the low quality level single layer encodings.

Table 13: Overview of frame–level statistics of aggregated temporal scalable video traffic

		Compr.	Frame Size			Bit Rate		Corr.
		ratio	Mean	CoV	Peak/Mean	Mean	Peak	Corr.
Enc. M.	Video	YUV:MP4	$\bar{X}$ [kbyte]	CoV_X	$X_{\max}/\bar{X}$	$\bar{X}/T$ [Mbps]	$X_{\max}/T$ [Mbps]	$\rho_{be}^{(3)}$
QCIF	*Citizen Kane*	19.992	1.902	0.842	8.884	0.456	4.054	0.816
H.Q.	*Die Hard I*	13.702	2.774	0.519	4.692	0.666	3.124	0.224
No R.C.	*Jurassic Park I*	11.644	3.265	0.660	5.901	0.784	4.624	0.308
	Silence of the Lambs	20.212	1.881	0.774	8.782	0.451	3.964	0.769
	Star Wars IV	16.538	2.299	0.609	7.614	0.552	4.201	0.818
	Star Wars V	11.017	3.451	0.532	4.461	0.828	3.694	0.256
	The Firm	14.711	2.584	0.665	6.282	0.620	3.896	0.263
	Terminator I	12.960	2.933	0.624	8.332	0.704	5.865	0.254
	Total Recall	13.325	2.853	0.548	5.266	0.685	3.606	0.240
	Aladdin	6.927	5.488	0.404	4.201	1.317	5.533	0.276
	Cinderella	9.844	3.862	0.528	6.781	0.927	6.285	0.264
	Baseball with Comm	9.216	4.125	0.399	4.097	0.990	4.056	0.227
	Snowboard with Comm	8.049	4.723	0.477	5.446	1.134	6.174	0.268
	Oprah w/o Comm	6.787	5.601	0.395	2.932	1.344	3.941	0.242
	Tonight Show w/o Comm	13.879	2.739	0.881	6.616	0.657	4.349	0.337
	Lecture-Gupta	7.325	5.190	0.314	3.212	1.246	4.000	0.212
	Lecture-Reisslein	6.715	5.661	0.429	4.730	1.359	6.426	0.256
QCIF	*Jurassic Park I*	40.198	0.946	1.021	9.382	0.227	2.130	0.879
H.–M.Q.	*Star Wars IV*	62.284	0.610	1.041	16.371	0.146	2.398	0.908
No R.C.	*The Firm*	56.964	0.667	1.172	11.977	0.160	1.918	0.904
	Tonight Show w/o Comm	53.024	0.717	1.363	13.181	0.172	2.268	0.909
QCIF	*Citizen Kane*	97.176	0.391	1.798	21.487	0.094	2.017	0.977
M.Q.	*Die Hard I*	75.078	0.506	1.341	13.621	0.122	1.655	0.960
No R.C.	*Jurassic Park I*	64.821	0.586	1.572	15.129	0.141	2.130	0.971
	Silence of the Lambs	114.620	0.332	1.672	25.477	0.080	2.028	0.956
	Star Wars IV	92.471	0.411	1.497	24.305	0.099	2.398	0.970
	Star Wars V	74.043	0.513	1.500	13.965	0.123	1.721	0.967
	The Firm	88.542	0.429	1.733	17.855	0.103	1.840	0.976
	Terminator I	61.397	0.619	1.267	11.856	0.149	1.762	0.939
	Total Recall	75.479	0.504	1.406	13.120	0.121	1.586	0.965
	Aladdin	43.361	0.877	1.221	10.659	0.210	2.243	0.938
	Cinderella	59.591	0.638	1.340	17.686	0.153	2.708	0.943
	Baseball with Comm	63.296	0.601	1.294	12.902	0.144	1.860	0.962
	Snowboard with Comm	45.396	0.837	1.174	12.792	0.201	2.571	0.949
	Oprah w/o Comm	50.186	0.758	1.330	10.046	0.182	1.826	0.972
	Tonight Show w/o Comm	87.114	0.436	2.139	20.124	0.105	2.108	0.981
	Lecture-Gupta	50.414	0.754	1.405	12.256	0.181	2.218	0.985
	Lecture-Reisslein	47.504	0.800	1.385	12.783	0.192	2.455	0.977
QCIF	*Jurassic Park I*	117.346	0.324	1.096	11.569	0.078	0.900	0.925
M.–L.Q.	*Star Wars IV*	140.727	0.270	1.044	19.627	0.065	1.272	0.922
No R.C.	*The Firm*	146.581	0.259	1.171	12.601	0.062	0.784	0.930
	Tonight Show w/o Comm	166.889	0.228	1.565	19.215	0.055	1.050	0.944
QCIF	*Citizen Kane*	177.433	0.214	1.091	12.746	0.051	0.655	0.927
L.Q.	*Die Hard I*	130.258	0.292	0.855	9.172	0.070	0.642	0.889
No R.C.	*Jurassic Park I*	138.488	0.275	0.983	10.575	0.066	0.697	0.918
	Silence of the Lambs	178.585	0.213	0.885	13.426	0.051	0.686	0.847
	Star Wars IV	154.741	0.246	0.930	17.417	0.059	1.027	0.912
	Star Wars V	142.461	0.267	0.949	10.129	0.064	0.649	0.906
	The Firm	164.951	0.230	1.019	10.713	0.055	0.593	0.915
	Terminator I	117.157	0.324	0.849	10.598	0.078	0.825	0.863
	Total Recall	134.664	0.282	0.891	8.208	0.068	0.556	0.896
	Aladdin	100.297	0.379	0.923	9.371	0.091	0.852	0.882
	Cinderella	122.791	0.310	0.899	14.851	0.074	1.104	0.875
	Baseball with Comm	124.231	0.306	0.861	8.219	0.073	0.604	0.890
	Snowboard with Comm	97.214	0.391	0.833	8.833	0.094	0.829	0.888
	Oprah w/o Comm	137.330	0.277	0.988	8.561	0.066	0.569	0.933
	Tonight Show w/o Comm	198.737	0.191	1.390	17.926	0.046	0.823	0.936
	Lecture-Gupta	133.533	0.285	1.294	12.206	0.068	0.834	0.974
	Lecture-Reisslein	130.916	0.290	1.229	14.529	0.070	1.013	0.961
QCIF	*Citizen Kane*	88.609	0.429	1.229	23.003	0.103	2.369	0.888
R.C.	*Die Hard I*	74.264	0.512	0.872	18.408	0.123	2.262	0.819
64 kbps	*Jurassic Park I*	67.103	0.567	0.876	14.762	0.136	2.007	0.702
	Silence of the Lambs	90.486	0.420	1.133	17.016	0.101	1.716	0.874
	Star Wars IV	84.539	0.450	1.025	32.596	0.108	3.518	0.872
	Star Wars V	68.500	0.555	0.851	14.572	0.133	1.941	0.701
	The Firm	81.984	0.464	1.103	25.230	0.111	2.808	0.843
	Terminator I	62.361	0.610	0.768	25.859	0.146	3.783	0.640
	Total Recall	74.564	0.510	0.891	13.026	0.122	1.594	0.815
	Aladdin	46.718	0.814	0.627	17.331	0.195	3.385	0.345
	Cinderella	62.189	0.611	0.796	30.748	0.147	4.511	0.659

Table 13: *continued*

		Compr.	Frame Size			Bit Rate		Corr.
		ratio	Mean	CoV	Peak/Mean	Mean	Peak	Corr.
Enc. M.	Video	YUV:MP4	$\bar{X}$ [kbyte]	CoV_X	$X_{\max}/\bar{X}$	$\bar{X}/T$ [Mbps]	$X_{\max}/T$ [Mbps]	$\rho_{be}^{(3)}$
	Baseball with Comm	65.189	0.583	0.735	23.602	0.140	3.303	0.734
	Snowboard with Comm	47.166	0.806	0.583	17.042	0.193	3.297	0.369
	Oprah w/o Comm	60.119	0.632	0.735	16.581	0.152	2.516	0.718
	Tonight Show w/o Comm	74.693	0.509	1.008	13.370	0.122	1.633	0.811
	Lecture-Gupta	55.125	0.690	0.851	10.778	0.166	1.784	0.767
	Lecture-Reisslein	46.204	0.823	0.613	26.491	0.197	5.231	0.424
QCIF	*Citizen Kane*	58.272	0.652	1.394	9.832	0.157	1.539	0.983
R.C.	*Die Hard I*	53.606	0.709	1.149	8.534	0.170	1.452	0.974
128 kbps	*Jurassic Park I*	52.852	0.719	1.206	8.471	0.173	1.462	0.952
	Silence of the Lambs	57.190	0.665	1.255	10.091	0.160	1.610	0.977
	Star Wars IV	56.347	0.675	1.224	8.775	0.162	1.421	0.981
	Star Wars V	51.723	0.735	1.087	7.693	0.176	1.357	0.956
	The Firm	56.442	0.674	1.317	10.353	0.162	1.674	0.979
	Terminator I	49.395	0.770	1.034	9.524	0.185	1.759	0.937
	Total Recall	54.234	0.701	1.174	9.808	0.168	1.650	0.975
	Aladdin	41.269	0.921	0.849	10.872	0.221	2.404	0.845
	Cinderella	49.027	0.775	1.050	11.642	0.186	2.166	0.931
	Baseball with Comm	49.664	0.765	1.002	7.495	0.184	1.377	0.961
	Snowboard with Comm	41.392	0.918	0.817	7.843	0.220	1.729	0.885
	Oprah w/o Comm	46.946	0.810	1.024	7.708	0.194	1.498	0.953
	Tonight Show w/o Comm	53.831	0.706	1.277	9.322	0.169	1.580	0.971
	Lecture-Gupta	44.395	0.856	1.043	6.109	0.206	1.255	0.962
	Lecture-Reisslein	41.028	0.927	0.841	6.121	0.222	1.361	0.925
QCIF	*Citizen Kane*	32.316	1.176	1.391	10.578	0.282	2.987	0.997
R.C.	*Die Hard I*	30.826	1.233	1.244	9.105	0.296	2.695	0.994
256 kbps	*Jurassic Park I*	31.195	1.219	1.320	8.783	0.292	2.569	0.992
	Silence of the Lambs	31.920	1.191	1.303	9.510	0.286	2.718	0.996
	Star Wars IV	31.780	1.196	1.295	8.546	0.287	2.454	0.997
	Star Wars V	30.791	1.235	1.237	8.630	0.296	2.557	0.994
	The Firm	31.935	1.190	1.351	10.237	0.286	2.925	0.997
	Terminator I	29.807	1.275	1.183	8.271	0.306	2.532	0.987
	Total Recall	31.164	1.220	1.267	8.729	0.293	2.556	0.995
	Aladdin	27.495	1.383	1.059	6.561	0.332	2.177	0.970
	Cinderella	29.725	1.279	1.190	8.299	0.307	2.547	0.985
	Baseball with Comm	29.822	1.275	1.171	7.955	0.306	2.434	0.993
	Snowboard with Comm	27.418	1.387	1.049	8.005	0.333	2.664	0.982
	Oprah w/o Comm	28.994	1.311	1.186	8.277	0.315	2.605	0.991
	Tonight Show w/o Comm	31.492	1.207	1.364	8.561	0.290	2.480	0.995
	Lecture-Gupta	28.433	1.337	1.162	6.673	0.321	2.141	0.996
	Lecture-Reisslein	27.508	1.382	1.065	5.415	0.332	1.796	0.993

Table 14: Overview of GoP–level statistics of aggregated temporal scalable video traffic

		GoP Size			Bit Rate	Corr.
		Mean	CoV	Peak/Mean	Peak	Corr.
Enc. M.	Video	$\bar{Y}$ [kbyte]	CoV_Y	$Y_{\max}/\bar{Y}$	$Y_{\max}/T$ [Mbps]	$\rho_{be}^{(G)}$
QCIF	*Citizen Kane*	22.819	0.558	4.793	2.188	0.978
H.Q.	*Die Hard I*	33.294	0.298	2.624	1.747	0.978
No R.C.	*Jurassic Park I*	39.178	0.458	4.664	3.655	0.978
	Silence of the Lambs	22.571	0.586	7.372	3.328	0.989
	Star Wars IV	27.584	0.383	5.061	2.792	0.985
	Star Wars V	41.407	0.388	2.676	2.216	0.989
	The Firm	31.010	0.450	4.223	2.619	0.985
	Terminator I	35.199	0.426	4.027	2.835	0.972
	Total Recall	34.236	0.339	3.174	2.174	0.981
	Aladdin	65.857	0.288	2.767	3.645	0.978
	Cinderella	46.341	0.388	5.079	4.707	0.970
	Baseball with Comm	49.502	0.284	2.707	2.681	0.984
	Snowboard with Comm	56.678	0.387	4.173	4.731	0.979
	Oprah w/o Comm	67.210	0.318	2.012	2.705	0.965
	Tonight Show w/o Comm	32.868	0.709	4.553	2.993	0.989
	Lecture-Gupta	62.278	0.225	2.033	2.532	0.996
	Lecture-Reisslein	67.932	0.383	2.033	2.763	0.998
QCIF	*Jurassic Park I*	11.349	0.584	6.509	1.477	0.970
H.–M.Q.	*Star Wars IV*	7.324	0.538	7.928	1.161	0.972
No R.C.	*The Firm*	8.008	0.659	6.072	0.973	0.977
	Tonight Show w/o Comm	8.603	0.802	6.621	1.139	0.972
QCIF	*Citizen Kane*	4.694	0.572	5.691	0.534	0.960
M.Q.	*Die Hard I*	6.076	0.445	3.731	0.453	0.939
No R.C.	*Jurassic Park I*	7.038	0.543	6.236	0.878	0.955
	Silence of the Lambs	3.980	0.732	12.348	0.983	0.965
	Star Wars IV	4.933	0.507	7.343	0.725	0.956
	Star Wars V	6.161	0.559	4.280	0.527	0.961
	The Firm	5.152	0.604	5.575	0.574	0.963
	Terminator I	7.430	0.514	5.345	0.794	0.940
	Total Recall	6.044	0.471	3.984	0.482	0.941
	Aladdin	10.521	0.513	4.523	0.952	0.958
	Cinderella	7.655	0.535	9.481	1.452	0.947
	Baseball with Comm	7.207	0.458	3.935	0.567	0.939
	Snowboard with Comm	10.049	0.482	6.054	1.217	0.943
	Oprah w/o Comm	9.090	0.377	3.624	0.659	0.930
	Tonight Show w/o Comm	5.237	0.770	6.453	0.676	0.963
	Lecture-Gupta	9.049	0.315	2.818	0.510	0.981
	Lecture-Reisslein	9.603	0.480	3.078	0.591	0.990
QCIF	*Jurassic Park I*	3.888	0.488	5.121	0.398	0.940
M.–L.Q.	*Star Wars IV*	3.242	0.455	6.130	0.397	0.943
No R.C.	*The Firm*	3.112	0.514	4.443	0.277	0.977
	Tonight Show w/o Comm	2.734	0.749	6.042	0.330	0.966
QCIF	*Citizen Kane*	2.571	0.428	3.839	0.197	0.937
L.Q.	*Die Hard I*	3.502	0.408	3.076	0.215	0.936
No R.C.	*Jurassic Park I*	3.294	0.429	4.000	0.264	0.923
	Silence of the Lambs	2.554	0.473	7.947	0.406	0.940
	Star Wars IV	2.948	0.403	5.111	0.301	0.931
	Star Wars V	3.202	0.441	3.547	0.227	0.932
	The Firm	2.766	0.441	3.468	0.192	0.932
	Terminator I	3.894	0.445	4.573	0.356	0.934
	Total Recall	3.388	0.424	3.231	0.219	0.929
	Aladdin	4.548	0.462	4.338	0.395	0.941
	Cinderella	3.715	0.449	8.442	0.627	0.934
	Baseball with Comm	3.672	0.421	3.899	0.286	0.927
	Snowboard with Comm	4.693	0.395	4.847	0.455	0.893
	Oprah w/o Comm	3.322	0.370	4.005	0.266	0.912
	Tonight Show w/o Comm	2.295	0.673	5.270	0.242	0.967
	Lecture-Gupta	3.416	0.254	3.297	0.225	0.939
	Lecture-Reisslein	3.485	0.412	3.662	0.255	0.967
QCIF	*Citizen Kane*	5.148	0.435	5.001	0.515	0.298
R.C.	*Die Hard I*	6.143	0.360	3.031	0.372	0.285
64 kbps	*Jurassic Park I*	6.798	0.473	4.842	0.658	0.316
	Silence of the Lambs	5.042	0.441	7.704	0.777	0.372
	Star Wars IV	5.396	0.391	6.355	0.686	0.400
	Star Wars V	6.660	0.468	3.602	0.480	0.358
	The Firm	5.564	0.456	4.405	0.490	0.269
	Terminator I	7.315	0.433	4.261	0.623	0.335
	Total Recall	6.118	0.376	3.341	0.409	0.262
	Aladdin	9.765	0.438	4.170	0.814	0.580
	Cinderella	7.336	0.444	7.982	1.171	0.405
	Baseball with Comm	6.998	0.359	3.440	0.481	0.364
	Snowboard with Comm	9.672	0.395	4.687	0.907	0.510
	Oprah w/o Comm	7.588	0.350	3.583	0.544	0.275
	Tonight Show w/o Comm	6.108	0.444	4.476	0.547	0.303
	Lecture-Gupta	8.276	0.346	2.980	0.493	0.413
	Lecture-Reisslein	9.873	0.381	3.632	0.717	0.402
QCIF	*Citizen Kane*	7.829	0.191	3.224	0.505	0.237
R.C.	*Die Hard I*	8.510	0.176	2.180	0.371	0.276

Table 14: *continued*

		GoP Size			Bit Rate	Corr.
		Mean	CoV	Peak/Mean	Peak	Corr.
Enc. M.	Video	$\bar{Y}$ [kbyte]	CoV_Y	$Y_{\max}/\bar{Y}$	$Y_{\max}/T$ [Mbps]	$\rho_{be}^{(G)}$
128 kbps	*Jurassic Park I*	8.632	0.277	3.844	0.664	0.149
	Silence of the Lambs	7.977	0.205	4.866	0.776	0.178
	Star Wars IV	8.096	0.178	4.071	0.659	0.336
	Star Wars V	8.820	0.230	2.689	0.474	0.187
	The Firm	8.083	0.202	2.997	0.484	0.265
	Terminator I	9.236	0.249	3.382	0.625	0.190
	Total Recall	8.412	0.181	2.468	0.415	0.310
	Aladdin	11.054	0.319	3.535	0.781	0.241
	Cinderella	9.305	0.279	6.430	1.197	0.296
	Baseball with Comm	9.186	0.199	2.647	0.486	0.254
	Snowboard with Comm	11.021	0.274	4.350	0.959	0.231
	Oprah w/o Comm	9.717	0.222	3.037	0.590	0.167
	Tonight Show w/o Comm	8.475	0.232	3.283	0.556	0.204
	Lecture-Gupta	10.276	0.176	2.311	0.475	0.228
	Lecture-Reisslein	11.119	0.211	2.268	0.504	0.111
QCIF R.C. 256 kbps	*Citizen Kane*	14.116	0.080	1.907	0.538	0.336
	Die Hard I	14.799	0.088	1.552	0.459	0.315
	Jurassic Park I	14.624	0.127	2.524	0.738	0.205
	Silence of the Lambs	14.292	0.091	2.926	0.836	0.194
	Star Wars IV	14.355	0.076	2.317	0.665	0.360
	Star Wars V	14.816	0.096	1.897	0.562	0.290
	The Firm	14.285	0.085	1.839	0.525	0.326
	Terminator I	15.305	0.127	2.349	0.719	0.246
	Total Recall	14.638	0.089	1.714	0.502	0.331
	Aladdin	16.592	0.168	2.777	0.922	0.267
	Cinderella	15.347	0.143	4.032	1.238	0.260
	Baseball with Comm	15.297	0.103	1.854	0.567	0.253
	Snowboard with Comm	16.639	0.146	3.167	1.054	0.290
	Oprah w/o Comm	15.734	0.119	2.010	0.632	0.188
	Tonight Show w/o Comm	14.486	0.103	2.131	0.617	0.249
	Lecture-Gupta	16.044	0.066	1.678	0.538	0.309
	Lecture-Reisslein	16.584	0.083	2.116	0.702	0.174

3 Analysis of Video Quality

In this section we study the video quality of the base layer stream and the aggregate (base + enhancement layer) stream. This quality analysis focuses on the quality of the luminance component.

3.1 Base Layer Quality

We first consider the base layer. Recall that $Q_n^{b,Y}$, $n = 0, \ldots, N-1$, denotes the PSNR quality (in dB) of the luminance component in frame n. For convenience, we write Q_n^b for $Q_n^{b,Y}$, and M_n^b for the corresponding MSE quality, i.e., $M_n^b = p^2/(10^{(Q_n/10)})$.

Table 15 gives the average qualities ($\bar{Q}^b$), the coefficients of quality variation ($CoQV^b$ and $CoQV'^b$), and the quality ranges ($Q_{\text{min}}^{\text{max},b}$) for the decoded base layer stream. The quality statistics are provided for the frame-level and the GoP-level.

Table 15: Overview of quality statistics of base layer of temporal scalable encoded video

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^b$	$CoQV^b$	$CoQV'^b$	$Q_{\text{min}}^{\text{max},b}$	$CoQC^{(G),b}$	$CoQV'^{(G),b}$	$Q_{\text{min}}^{\text{max},(G),b}$
QCIF	*Citizen Kane*	27.107	4.731	0.176	48.584	2.294	0.125	33.018
H.Q.	*Die Hard I*	23.029	2.543	0.248	46.535	1.311	0.182	28.672
No R.C.	*Jurassic Park I*	24.882	2.725	0.215	41.584	1.394	0.15	30.544
	Silence of the Lambs	27.623	3.182	0.168	44.522	1.717	0.118	28.047
	Star Wars IV	25.137	3.678	0.203	49.056	1.562	0.148	27.417
	Star Wars V	24.894	4.144	119.176		2.012	79.682	43.548
	The Firm	25.89	3.435	0.188	41.199	1.602	0.132	27.468
	Terminator I	22.119	2.959	0.272	49.515	1.428	0.207	37.210
	Total Recall	23.937	2.962	0.227	47.17	1.447	0.164	27.215
	Aladdin	21.253	2.497	0.278	46.696	1.228	0.213	26.338
	Cinderella	22.783	2.695	0.248	36.444	1.314	0.189	29.511
	Baseball with Comm	22.735	3.351	0.243	63.502	1.679	0.17	31.996
	Snowboard with Comm	20.944	2.292	0.298	48.142	1.184	0.215	26.922
	Oprah w/o Comm	25.069	2.377	0.205	44.45	1.231	0.13	25.067
	Tonight Show w/o Comm	27.584	3.137	0.255	41.749	1.852	0.239	34.008
	Lecture-Gupta	28.072	2.393	0.157	37.137	1.168	0.074	27.288
	Lecture-Reisslein	26.837	1.504	0.2	42.672	0.873	0.14	34.828
QCIF	*Jurassic Park I*	24.437	2.406	0.165	36.305	1.231	0.117	29.096
H.–M.Q.	*Star Wars IV*	24.845	3.402	0.168	42.186	1.45	0.124	25.680
No R.C.	*The Firm*	25.454	3.063	0.152	36.991	1.43	0.114	26.456
	Tonight Show w/o Comm	26.809	2.587	0.234	37.773	1.541	0.227	29.750
QCIF	*Citizen Kane*	26.254	3.85	0.14	42.501	1.864	0.11	32.816
M.Q.	*Die Hard I*	22.797	2.378	0.199	40.334	1.227	0.142	27.186
No R.C.	*Jurassic Park I*	24.283	2.313	0.16	36.305	1.189	0.117	29.052
	Silence of the Lambs	27.047	2.726	0.139	37.674	1.49	0.11	27.118
	Star Wars IV	24.744	3.327	0.165	42.192	1.416	0.124	25.576
	Star Wars V	23.789	2.991	0.181	41.598	1.389	0.144	33.198
	The Firm	25.32	2.958	0.15	36.989	1.386	0.116	26.464
	Terminator I	21.906	2.784	0.214	44.323	1.34	0.157	33.469
	Total Recall	23.605	2.704	0.18	40.51	1.327	0.131	26.083
	Aladdin	21.093	2.362	0.215	39.898	1.168	0.156	25.327
	Cinderella	22.523	2.491	0.194	35.533	1.224	0.139	29.057
	Baseball with Comm	22.474	3.122	0.19	63.49	1.569	0.139	31.928
	Snowboard with Comm	20.797	2.172	0.229	42.241	1.127	0.164	26.623
	Oprah w/o Comm	24.572	2.051	0.128	41.619	1.076	0.09	24.593
	Tonight Show w/o Comm	26.62	2.462	0.241	37.773	1.48	0.235	29.797
	Lecture-Gupta	26.768	1.731	0.08	36.764	0.879	0.053	26.433
	Lecture-Reisslein	25.817	1.133	0.168	37.761	0.734	0.155	29.981
QCIF	*Jurassic Park I*	23.422	1.829	0.132	34.316	0.947	0.102	27.297
M.–L.Q.	*Star Wars IV*	24.136	2.859	0.146	38.707	1.221	0.114	24.545
No R.C.	*The Firm*	24.431	0.848	0.132	34.188	0.980	0.108	24.984
	Tonight Show w/o Comm	25.067	1.681	0.264	37.113	1.072	0.262	29.290
QCIF	*Citizen Kane*	24.583	2.574	0.12	40.032	1.261	0.103	32.118
L.Q.	*Die Hard I*	22.165	1.992	0.16	35.521	1.031	0.115	24.975
No R.C.	*Jurassic Park I*	23.081	1.675	0.126	34.212	0.871	0.1	26.905
	Silence of the Lambs	25.828	1.993	0.123	33.875	1.14	0.106	25.291
	Star Wars IV	23.858	2.673	0.142	36.486	1.154	0.112	24.442

Table 15: *continued*

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^b$	$CoQV^b$	$CoQV'^b$	$Q_{\min}^{\max,b}$	$CoQC^{(G),b}$	$CoQV'^{(G),b}$	$Q_{\min}^{\max,(G),b}$
	Star Wars V	22.945	2.416	0.161	37.131	1.147	0.137	28.987
	The Firm	24.088	2.162	0.13	33.713	1.04	0.108	24.612
	Terminator I	21.377	2.414	0.176	39.727	1.165	0.132	32.002
	Total Recall	22.812	2.21	0.147	34.88	1.088	0.11	24.099
	Aladdin	20.581	2.036	0.177	35.982	1.024	0.134	24.161
	Cinderella	21.828	2.052	0.155	34.44	1.015	0.115	27.889
	Baseball with Comm	21.798	2.635	0.16	46.899	1.318	0.123	31.532
	Snowboard with Comm	20.279	1.878	0.183	39.852	0.972	0.137	25.693
	Oprah w/o Comm	23.362	1.473	0.094	41.818	0.789	0.074	23.775
	Tonight Show w/o Comm	24.564	1.494	0.283	38.231	0.989	0.282	30.179
	Lecture-Gupta	23.346	0.794	0.072	37.047	0.471	0.068	26.882
	Lecture-Reisslein	23.274	0.71	0.172	36.469	0.579	0.17	28.752
QCIF R.C. 64 kbps	*Citizen Kane*	25.76	3.434	0.16	50.825	1.726	0.143	32.721
	Die Hard I	22.55	2.213	0.194	48.358	1.169	0.154	28.192
	Jurassic Park I	23.64	1.953	0.161	37.721	1.045	0.136	30.301
	Silence of the Lambs	26.853	2.591	0.158	47.586	1.495	0.137	27.90
	Star Wars IV	24.468	3.103	0.174	48.765	1.363	0.145	27.266
	Star Wars V	23.347	2.675	0.204	49.347	1.274	0.168	34.188
	The Firm	24.862	2.646	0.164	38.528	1.301	0.142	27.25
	Terminator I	21.613	2.574	0.21	51.49	1.257	0.172	34.451
	Total Recall	23.267	2.486	0.181	47.667	1.246	0.149	27.186
	Aladdin	20.653	2.08	0.195	40.538	1.054	0.156	25.550
	Cinderella	22.131	2.226	0.185	40.523	1.119	0.147	29.249
	Baseball with Comm	22.103	2.853	0.185	59.814	1.443	0.151	31.689
	Snowboard with Comm	20.35	1.909	0.205	44.257	1	0.159	26.964
	Oprah w/o Comm	23.88	1.695	0.114	42.168	0.931	0.093	24.470
	Tonight Show w/o Comm	25.504	1.875	0.343	43.595	1.228	0.343	36.004
	Lecture-Gupta	24.552	1.107	0.091	39.339	0.696	0.084	27.203
	Lecture-Reisslein	23.735	0.826	0.213	44.409	0.678	0.21	36.270
QCIF R.C. 128 kbps	*Citizen Kane*	26.538	4.127	0.166	53.018	2.044	0.139	32.753
	Die Hard I	22.86	2.421	0.215	53.448	1.254	0.162	28.659
	Jurassic Park I	24.276	2.313	0.178	38.432	1.209	0.141	30.092
	Silence of the Lambs	27.292	2.892	0.161	50.02	1.622	0.13	28.024
	Star Wars IV	24.864	3.424	0.185	52.005	1.476	0.146	27.468
	Star Wars V	23.781	2.99	0.211	52.059	1.404	0.167	34.448
	The Firm	25.42	3.041	0.17	40.937	1.454	0.138	27.131
	Terminator I	21.915	2.785	0.233	54.978	1.354	0.184	35.685
	Total Recall	23.677	2.772	0.196	51.874	1.364	0.152	27.128
	Aladdin	20.976	2.284	0.217	45.56	1.15	0.17	25.542
	Cinderella	22.501	2.463	0.206	37.192	1.224	0.159	28.937
	Baseball with Comm	22.459	3.12	0.199	63.475	1.568	0.152	31.660
	Snowboard with Comm	20.688	2.102	0.236	49.709	1.1	0.179	26.871
	Oprah w/o Comm	24.469	1.988	0.134	44.857	1.07	0.103	24.853
	Tonight Show w/o Comm	26.54	2.411	0.306	44.027	1.506	0.304	35.627
	Lecture-Gupta	26.19	1.553	0.091	37.873	0.881	0.074	26.993
	Lecture-Reisslein	25.156	1.041	0.19	45.216	0.766	0.183	35.721
QCIF R.C. 256 kbps	*Citizen Kane*	26.962	4.577	0.179	57.526	2.227	0.139	32.420
	Die Hard I	22.972	2.497	0.235	55.339	1.296	0.174	28.646
	Jurassic Park I	24.65	2.551	0.198	41.559	1.321	0.148	29.978
	Silence of the Lambs	27.508	3.088	0.172	52.62	1.681	0.129	27.914
	Star Wars IV	25.046	3.598	0.2	55.419	1.532	0.151	27.650
	Star Wars V	24.006	3.175	0.224	54.91	1.472	0.171	34.351
	The Firm	25.719	3.288	0.181	45.887	1.55	0.138	27.181
	Terminator I	22.052	2.905	0.256	58.091	1.405	0.199	37.043
	Total Recall	23.847	2.902	0.214	54.475	1.421	0.159	26.866
	Aladdin	21.144	2.402	0.237	50.88	1.197	0.182	26.028
	Cinderella	22.677	2.6	0.226	38.899	1.278	0.173	28.754
	Baseball with Comm	22.623	3.245	0.218	63.463	1.632	0.158	31.428
	Snowboard with Comm	20.842	2.218	0.261	53.537	1.149	0.192	26.604
	Oprah w/o Comm	24.8	2.199	0.159	45.318	1.16	0.114	24.901
	Tonight Show w/o Comm	27.182	2.844	0.278	44.412	1.713	0.273	35.106
	Lecture-Gupta	27.255	1.969	0.107	40.319	1.013	0.066	26.799
	Lecture-Reisslein	26.072	1.234	0.181	45.36	0.801	0.161	35.095

For the encodings without rate control we observe that the average qualities of the base layer are significantly (5–10 dB) smaller than the average qualities of the corresponding single layer encodings (see Table 6 of Part 2). Also, the alternative coefficients of variation of the base layer are roughly one order of magnitude larger than for the single layer encodings. The quality range of the base layer is also significantly larger. Thus, we conclude that skipping the B frames reduces the video quality quite significantly with respect to the single layer encodings. In particular, the temporal base layer has significant variations in the displayed video quality since only every third frame is decoded and is displayed in place of the missing frames in between. The reduction in quality with respect to the single layer encodings is not as severe for the rate-controlled sequences. There are two effects at work here. First, the base layer (i.e., the I and P frames) is allocated the full target bit rate in the temporal scalable encodings, whereas the target bit rate needs to accommodate all frame types (I, P as well as B frames) in the single layer encodings. Thus, in the temporal scalable encoder, more bits can be allocated to the I and P frames, i.e., these are encoded at a higher quality.

The second effect is again the skipping of the B frames, which reduces the quality of the displayed video. As we note by comparing the Table 13 here with Table 6 in Part 2, this second effect dominates, especially for the 64 kbps and 128 kbps base layer encodings.

Figure 26 gives the video frame qualities Q_n^b (in dB) as a function of the frame number n. These plots clearly illustrate the severe impact of the missing B frames on the video quality. This effect becomes especially apparent by comparing these plots here with the corresponding single layer plots in Figure 11 of Part 2.

Figure 27 gives the histogram of the frame qualities Q_n^b. Figure 28 gives the MSE autocorrelation coefficient $\rho_M(k)$ as a function of lag k (in frames). All of the $\rho_M(k)$ plots exhibit periodic spikes that are spaced 3 frames apart. These periodic spikes are due to the fact that every third frame is actually a decoded I or P frame — giving a relatively high PSNR — whereas the two frames in between are approximated by the preceding decoded frame, giving relatively low PSNR. From these plots and also the plots in Figure 29, which give the MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of the lag k (in GoPs), we observe that the MSE autocorrelations of the base layer drop off relatively quickly to levels around 0.1 for lags of 100 GoPs. This is in contrast to the MSE autocorrelations of the single layer encodings, (see Figure 13 of Part 2) which drop off more slowly and remain at higher levels for large lags.

3.2 Quality of Aggregate Video Stream

We now proceed to study the quality of the aggregate stream. Recall that $Q_n^{e,Y}$, $n = 0, \ldots, N-1$, denotes the improvement in the PSNR quality (in dB) of the luminance component in frame n, achieved by adding the enhancement layer. We denote Q_n^{agg}, $n = 0, \ldots, N-1$, for the PSNR quality (in dB) of the luminance component in the decoded aggregate stream. By definition, $Q_n^{\text{agg}} = Q_n^b + Q_n^e$, $n = 0, \ldots, N-1$. We denote M_n^{agg}, $n = 0, \ldots, N-1$, for the corresponding MSE quality.

Table 16 gives the average qualities ($\bar{Q}^{agg}$), the coefficients of quality variation ($CoQV^{agg}$), and the quality ranges ($Q_{\text{min}}^{\text{max},agg}$) for the decoded base layer stream. The quality statistics are provided for the frame-level and the GoP-level.

Table 16: Overview of quality statistics of the aggregate stream of temporal scalable encoded video

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^{agg}$	$CoQV^{agg}$	$CoQV'^{agg}$	$Q_{\text{min}}^{\text{max},agg}$	$CoQC^{(G),agg}$	$CoQV^{(G),agg}$	$Q_{\text{min}}^{\text{max},(G),agg}$
QCIF	*Citizen Kane*	37.64	0.487	0.03	31.76	0.263	0.026	17.008
H.Q.	*Die Hard I*	36.685	0.22	0.021	28.501	0.124	0.015	18.572
No R.C.	*Jurassic Park I*	36.565	0.197	0.026	15.013	0.158	0.02	6.000
	Silence of the Lambs	37.107	0.186	0.023	18.689	0.161	0.02	12.566
	Star Wars IV	37.078	0.221	0.034	22.773	0.194	0.03	11.960
	Star Wars V	35.991	17.159	0.051	50.579	7.011	0.048	41.750
	The Firm	36.721	0.162	0.02	17.324	0.122	0.014	7.939
	Terminator I	37.055	0.62	0.03	32.554	0.276	0.024	23.130
	Total Recall	36.65	0.166	0.02	26.262	0.112	0.014	11.889
	Aladdin	36.032	0.163	0.024	13.545	0.109	0.016	7.964
	Cinderella	36.328	0.74	0.021	26.737	0.349	0.013	17.791
	Baseball with Comm	35.996	0.205	0.025	42.467	0.124	0.018	12.087
	Snowboard with Comm	36.309	0.53	0.029	34.272	0.243	0.021	21.046
	Oprah w/o Comm	35.691	0.165	0.023	13.792	0.111	0.015	4.438
	Tonight Show w/o Comm	37.676	0.594	0.13	22.365	0.574	0.129	12.420
	Lecture-Gupta	36.215	0.164	0.023	7.186	0.105	0.014	5.899
	Lecture-Reisslein	35.992	0.748	0.045	34.134	0.37	0.041	26.002

Table 16: *continued*

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^{agg}$	$CoQV^{agg}$	$CoQV'^{agg}$	$Q_{\min}^{\max,agg}$	$CoQC^{(G),agg}$	$CoQV^{(G),agg}$	$Q_{\min}^{\max,(G),agg}$
QCIF	*Jurassic Park I*	30.786	0.353	0.054	20.109	0.336	0.052	12.430
H.–M.Q.	*Star Wars IV*	32.459	0.914	0.05	35.838	0.402	0.048	22.493
No R.C.	*The Firm*	31.758	0.359	0.047	16.451	0.346	0.045	10.734
	Tonight Show w/o Comm	31.834	0.616	0.165	18.966	0.607	0.165	15.835
QCIF	*Citizen Kane*	31.052	0.661	0.067	34.133	0.462	0.062	21.789
M.Q.	*Die Hard I*	30.843	0.43	0.051	28.654	0.312	0.043	17.678
No R.C.	*Jurassic Park I*	29.463	0.465	0.068	22.522	0.42	0.062	15.611
	Silence of the Lambs	31.892	0.577	0.064	24.519	0.544	0.061	16.753
	Star Wars IV	31.387	1.207	0.059	38.146	0.507	0.054	23.355
	Star Wars V	29.989	0.491	0.083	29.079	0.437	0.078	18.598
	The Firm	30.666	0.49	0.061	17.309	0.45	0.057	12.704
	Terminator I	30.21	1.05	0.068	39.179	0.485	0.059	25.839
	Total Recall	30.637	0.549	0.054	30.294	0.362	0.047	16.039
	Aladdin	28.893	0.553	0.058	31.986	0.338	0.047	15.916
	Cinderella	29.868	0.418	0.053	26.65	0.324	0.044	18.148
	Baseball with Comm	29.651	0.545	0.06	54.754	0.352	0.053	20.058
	Snowboard with Comm	28.988	0.48	0.074	28.438	0.409	0.064	14.783
	Oprah w/o Comm	28.473	0.326	0.053	25.34	0.282	0.045	12.530
	Tonight Show w/o Comm	30.682	0.683	0.185	20.991	0.654	0.184	18.747
	Lecture-Gupta	28.355	0.319	0.055	18.343	0.257	0.041	14.983
	Lecture-Reisslein	27.989	0.508	0.132	30	0.453	0.129	22.296
QCIF	*Jurassic Park I*	26.538	0.438	0.075	22.837	0.428	0.074	16.776
M.–L.Q.	*Star Wars IV*	28.748	1.127	0.07	36.829	0.54	0.068	23.582
No R.C.	*The Firm*	27.749	1.100	0.076	19.233	1.103	0.075	14.306
	Tonight Show w/o Comm	27.133	0.662	0.231	23.025	0.658	0.231	21.241
QCIF	*Citizen Kane*	26.909	0.542	0.082	33.695	0.472	0.08	23.160
L.Q.	*Die Hard I*	27.151	0.394	0.062	24.921	0.352	0.058	15.243
No R.C.	*Jurassic Park I*	25.682	0.447	0.08	22.615	0.44	0.078	17.430
	Silence of the Lambs	28.438	0.675	0.083	20.758	0.666	0.082	18.407
	Star Wars IV	27.89	1.033	0.074	34.936	0.547	0.072	23.203
	Star Wars V	26.605	0.549	0.102	25.603	0.529	0.1	17.950
	The Firm	26.902	0.555	0.082	21.491	0.548	0.081	15.322
	Terminator I	26.461	0.76	0.084	36.542	0.493	0.08	25.995
	Total Recall	27.032	0.432	0.066	25.233	0.388	0.063	15.437
	Aladdin	25.334	0.482	0.077	28.376	0.414	0.073	15.418
	Cinderella	26.109	0.403	0.065	26.53	0.38	0.063	19.590
	Baseball with Comm	26.299	0.452	0.078	37.748	0.398	0.074	19.526
	Snowboard with Comm	25.17	0.496	0.093	28.24	0.473	0.089	16.236
	Oprah w/o Comm	25.243	0.302	0.053	27.045	0.293	0.051	16.173
	Tonight Show w/o Comm	26.215	0.675	0.256	24.942	0.675	0.256	23.370
	Lecture-Gupta	23.855	0.314	0.065	21.977	0.307	0.064	20.018
	Lecture-Reisslein	24.06	0.523	0.158	28.512	0.517	0.158	22.154
QCIF	*Citizen Kane*	29.829	0.947	0.106	44.469	0.77	0.104	24.599
R.C.	*Die Hard I*	29.43	0.593	0.078	37.776	0.494	0.073	20.763
64 kbps	*Jurassic Park I*	27.625	0.621	0.099	25.515	0.564	0.096	19.303
	Silence of the Lambs	31.351	1.015	0.096	33.214	0.958	0.094	23.942
	Star Wars IV	30.391	1.439	0.09	46.216	0.74	0.086	27.963
	Star Wars V	28.487	0.769	0.143	34.732	0.693	0.14	24.078
	The Firm	29.316	0.806	0.098	21.177	0.758	0.095	16.456
	Terminator I	28.446	0.895	0.102	45.154	0.604	0.095	29.110
	Total Recall	29.195	0.682	0.085	39.803	0.546	0.081	17.514
	Aladdin	26.742	0.615	0.087	32.371	0.455	0.078	16.981
	Cinderella	28.049	0.566	0.081	30.802	0.488	0.076	20.071
	Baseball with Comm	28.102	0.596	0.088	50.146	0.484	0.082	19.472
	Snowboard with Comm	26.655	0.627	0.107	31.001	0.531	0.098	16.803
	Oprah w/o Comm	26.893	0.4	0.063	29.316	0.349	0.058	15.924
	Tonight Show w/o Comm	28.369	0.796	0.302	30.582	0.755	0.301	28.023
	Lecture-Gupta	26.042	0.505	0.076	24.431	0.448	0.07	19.213
	Lecture-Reisslein	25.732	0.649	0.184	35.905	0.58	0.182	29.275
QCIF	*Citizen Kane*	32.114	0.929	0.095	37.802	0.869	0.092	20.865
R.C.	*Die Hard I*	31.469	0.572	0.068	41.374	0.499	0.062	19.175
128 kbps	*Jurassic Park I*	29.481	0.707	0.096	22.925	0.675	0.093	19.383
	Silence of the Lambs	32.973	1.047	0.082	35.628	1	0.079	23.985
	Star Wars IV	32.286	1.126	0.08	45.808	0.737	0.074	25.037
	Star Wars V	30.144	0.779	0.131	33.135	0.732	0.127	23.900
	The Firm	31.165	0.818	0.086	23.073	0.783	0.083	16.298
	Terminator I	30.413	0.71	0.096	39.996	0.63	0.09	23.823
	Total Recall	31.158	0.719	0.074	42.924	0.559	0.07	17.538
	Aladdin	28.207	0.647	0.082	36.432	0.526	0.076	15.964
	Cinderella	29.845	0.618	0.076	27.038	0.546	0.071	19.898
	Baseball with Comm	29.717	0.611	0.076	54.937	0.484	0.071	21.618
	Snowboard with Comm	28.339	0.654	0.102	35.35	0.597	0.097	18.346
	Oprah w/o Comm	28.277	0.423	0.066	28.537	0.399	0.063	16.665
	Tonight Show w/o Comm	30.523	0.839	0.262	30.468	0.81	0.262	27.942
	Lecture-Gupta	27.847	0.5	0.068	22.548	0.466	0.063	19.266
	Lecture-Reisslein	27.275	0.632	0.162	36.701	0.601	0.161	29.266
QCIF	*Citizen Kane*	34.198	0.939	0.088	36.915	0.848	0.077	19.424
R.C.	*Die Hard I*	32.967	0.533	0.066	38.181	0.405	0.049	17.419
256 kbps	*Jurassic Park I*	31.397	0.76	0.09	24.689	0.702	0.081	18.639
	Silence of the Lambs	34.316	0.954	0.076	37.774	0.888	0.065	23.081
	Star Wars IV	33.745	0.727	0.077	40.218	0.603	0.062	21.531
	Star Wars V	31.67	0.731	0.122	35.326	0.655	0.112	22.265
	The Firm	32.842	0.767	0.077	25.835	0.701	0.067	16.155

Table 16: *continued*

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^{agg}$	$CoQV^{agg}$	$CoQV'^{agg}$	$Q_{\min}^{\max,agg}$	$CoQC^{(G),agg}$	$CoQV^{(G),agg}$	$Q_{\min}^{\max,(G),agg}$
	Terminator I	32.224	0.695	0.091	41.261	0.573	0.075	23.750
	Total Recall	32.72	0.599	0.07	41.391	0.467	0.055	15.765
	Aladdin	29.695	0.571	0.076	38.386	0.478	0.064	14.534
	Cinderella	31.455	0.676	0.074	29.127	0.544	0.061	20.721
	Baseball with Comm	31.008	0.507	0.075	46.342	0.413	0.06	17.641
	Snowboard with Comm	29.879	0.635	0.096	39.678	0.557	0.083	18.910
	Oprah w/o Comm	29.512	0.483	0.076	27.709	0.419	0.067	15.925
	Tonight Show w/o Comm	32.623	0.887	0.226	29.278	0.835	0.225	26.225
	Lecture-Gupta	29.282	0.47	0.073	22.808	0.384	0.053	17.379
	Lecture-Reisslein	28.639	0.59	0.146	31.091	0.531	0.141	25.332

For the encodings, without rate control we observe that the quality statistics of the aggregate streams match exactly the quality statistics of the corresponding single layer encodings.

For the encodings with rate control, we observe that the average quality increases by about 1.5–2 dB each time the base layer target bit rate is doubled from 64 kbps to 128 kbps and then from 128 kbps to 256 kbps. We also observe that the average PSNR qualities of the aggregate (base + enhancement layer) stream with a rate-controlled base layer are roughly 0.5–1.5 dB higher than the corresponding rate-controlled single layer streams.

Figure 30 gives the video frame qualities Q_n^{agg} (in dB) as a function of the frame number n. For the encodings without rate control the plots here match exactly the corresponding plots in Figure 11 of Part 2. For the encodings with rate control the plots here are very similar to the corresponding plots in Figure 11 of Part 2, the only apparent difference is that the plots here reach qualities that are just a few dB higher than in Figure 11 of Part 2. Similar observations hold for Figure 31 which gives the histogram of the frame qualities.

Figure 32 gives the MSE autocorrelation coefficient $\rho_M(k)$ as a function of lag k (in frames). Figure 33 gives the MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of lag k (in GoPs). We observe that the frame MSE autocorrelation functions $\rho_M(k)$ have a pronounced GoP periodicity at the high and medium quality levels (without rate control). The frame MSE autocorrelation function $\rho_M(k)$ for the encodings with rate control exhibit a pronounced 3-frame periodicity. The GoP MSE autocorrelations are generally significant, but lower than for the corresponding single layer encodings.

4 Correlation between Frame Sizes and Qualities

Table 17 gives the correlation coefficients between the quality and the frame size, both for the base layer and the aggregate stream. Both the MSE quality-to-frame size correlation (ρ_{XM}) and the PSNR quality-to-frame size correlation (ρ_{XQ}) are provided, for the frame level and the GoP aggregation level.

We observe several interesting trends in the quality-traffic correlations. For instance, ρ_{XQ} at the frame level is positive throughout and decreases in magnitude as the quality level decreases. The corresponding $\rho_{XQ}^{(G)}$, on the other hand, are negative throughout, and tend to be close to -1, especially for the lower quality levels. Similar trends can be observed for the other scenarios given in Table 17.

Overall, we conclude that there are non-trivial behaviors of the traffic-quality correlations in long encodings. We plan to study these in detail in future work. In particular, we plan to study the traffic and quality in conjunction with the video content features to uncover the fundamental characteristics of the traffic-quality correlations and their implications for video encoding and network transport.

Table 17: Correlation between quality and traffic for temporal scalable traces

		Base Layer				Aggregate Stream			
		Frame Level		GoP level		Frame Level		GoP level	
Enc. M.	Video	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$
QCIF	*Citizen Kane*	-0.106	0.466	0.437	-0.917	0.119	-0.179	0.623	-0.720
H.Q.	*Die Hard I*	-0.234	0.641	0.409	-0.567	-0.110	0.189	0.537	-0.559
No R.C.	*Jurassic Park I*	-0.204	0.604	0.360	-0.640	0.094	-0.050	0.718	-0.693

Table 17: *continued*

		Base Layer				Aggregate Stream			
		Frame Level		GoP level		Frame Level		GoP level	
Enc. M.	Video	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$
	Silence of the Lambs	-0.151	0.465	0.568	-0.840	0.250	-0.200	0.767	-0.716
	Star Wars IV	-0.151	0.563	0.347	-0.678	0.066	-0.074	0.603	-0.529
	Star Wars V	-0.137	-inf	0.292	-0.001	0.003	-0.243	0.028	-0.586
	The Firm	-0.154	0.540	0.474	-0.797	-0.006	0.071	0.732	-0.714
	Terminator I	-0.199	0.621	0.370	-0.580	0.027	-0.047	0.315	-0.466
	Total Recall	-0.196	0.618	0.377	-0.637	-0.099	0.150	0.640	-0.628
	Aladdin	-0.252	0.733	0.509	-0.606	-0.345	0.341	0.069	-0.079
	Cinderella	-0.223	0.644	0.478	-0.571	0.043	0.075	0.324	-0.684
	Baseball with Comm	-0.184	0.713	0.227	-0.526	-0.052	0.062	0.586	-0.555
	Snowboard with Comm	-0.266	0.736	0.348	-0.429	0.016	-0.040	0.313	-0.464
	Oprah w/o Comm	-0.252	0.768	0.424	-0.741	0.075	-0.012	0.798	-0.790
	Tonight Show w/o Comm	-0.141	0.092	0.565	-1.000	0.573	-0.641	0.879	-0.868
	Lecture-Gupta	-0.237	0.898	0.344	-0.611	-0.208	0.266	0.623	-0.614
	Lecture-Reisslein	-0.366	0.638	0.574	-0.985	0.174	-0.500	0.554	-0.831
QCIF	*Jurassic Park I*	-0.159	0.348	0.460	-0.816	0.319	-0.282	0.744	-0.656
H.–M.Q.	*Star Wars IV*	-0.119	0.325	0.448	-0.872	0.099	-0.200	0.527	-0.574
No R.C.	*The Firm*	-0.113	0.254	0.558	-0.953	0.343	-0.317	0.801	-0.744
	Tonight Show w/o Comm	-0.096	-0.057	0.700	-0.997	0.409	-0.419	0.821	-0.758
QCIF	*Citizen Kane*	-0.071	0.225	0.526	-0.989	0.039	-0.015	0.831	-0.762
M.Q.	*Die Hard I*	-0.171	0.398	0.576	-0.885	-0.047	0.103	0.636	-0.616
No R.C.	*Jurassic Park I*	-0.137	0.322	0.486	-0.834	0.026	0.018	0.828	-0.718
	Silence of the Lambs	-0.092	0.179	0.688	-0.937	0.193	-0.146	0.845	-0.723
	Star Wars IV	-0.105	0.298	0.469	-0.895	0.014	0.018	0.584	-0.665
	Star Wars V	-0.112	0.261	0.512	-0.892	0.059	-0.065	0.824	-0.705
	The Firm	-0.098	0.234	0.577	-0.958	0.074	-0.041	0.869	-0.815
	Terminator I	-0.150	0.396	0.472	-0.833	0.022	-0.001	0.577	-0.676
	Total Recall	-0.140	0.356	0.540	-0.944	-0.012	0.055	0.686	-0.709
	Aladdin	-0.179	0.422	0.581	-0.862	-0.008	0.089	0.758	-0.789
	Cinderella	-0.159	0.385	0.613	-0.856	0.012	0.075	0.824	-0.774
	Baseball with Comm	-0.126	0.394	0.390	-0.842	-0.039	0.085	0.660	-0.658
	Snowboard with Comm	-0.192	0.454	0.464	-0.669	0.016	0.011	0.810	-0.780
	Oprah w/o Comm	-0.150	0.434	0.595	-0.943	-0.142	0.192	0.887	-0.845
	Tonight Show w/o Comm	-0.081	-0.040	0.710	-0.987	0.145	-0.209	0.910	-0.782
	Lecture-Gupta	-0.130	0.578	0.468	-0.900	-0.356	0.457	0.921	-0.830
	Lecture-Reisslein	-0.190	0.166	0.724	-0.877	-0.043	-0.059	0.940	-0.821
QCIF	*Jurassic Park I*	-0.122	0.190	0.632	-0.954	0.233	-0.186	0.522	-0.407
M.–L.Q.	*Star Wars IV*	-0.106	0.192	0.580	-0.991	0.106	-0.201	0.438	-0.446
No R.C.	*The Firm*	-0.087	0.105	0.707	-1.034	0.250	-0.230	0.570	-0.515
	Tonight Show w/o Comm	-0.034	-0.141	0.857	-0.886	0.346	-0.325	0.744	-0.685
QCIF	*Citizen Kane*	-0.059	0.061	0.646	-0.980	0.213	-0.205	0.537	-0.466
L.Q.	*Die Hard I*	-0.181	0.313	0.713	-1.000	0.174	-0.160	0.254	-0.232
No R.C.	*Jurassic Park I*	-0.119	0.170	0.666	-0.959	0.206	-0.164	0.403	-0.307
	Silence of the Lambs	-0.076	0.057	0.796	-0.954	0.310	-0.266	0.536	-0.444
	Star Wars IV	-0.107	0.175	0.612	-1.000	0.121	-0.212	0.393	-0.402
	Star Wars V	-0.104	0.116	0.652	-0.961	0.264	-0.252	0.529	-0.510
	The Firm	-0.086	0.087	0.733	-1.000	0.221	-0.206	0.455	-0.414
	Terminator I	-0.149	0.276	0.599	-0.999	0.167	-0.221	0.382	-0.382
	Total Recall	-0.143	0.246	0.672	-1.000	0.192	-0.189	0.311	-0.304
	Aladdin	-0.162	0.244	0.693	-1.000	0.274	-0.283	0.606	-0.578
	Cinderella	-0.151	0.242	0.720	-1.000	0.292	-0.257	0.571	-0.501
	Baseball with Comm	-0.126	0.262	0.553	-1.000	0.167	-0.169	0.300	-0.299
	Snowboard with Comm	-0.181	0.310	0.623	-0.889	0.190	-0.197	0.401	-0.410
	Oprah w/o Comm	-0.104	0.176	0.711	-0.985	0.153	-0.131	0.358	-0.298
	Tonight Show w/o Comm	-0.015	-0.158	0.883	-0.866	0.366	-0.340	0.742	-0.698
	Lecture-Gupta	-0.040	0.052	0.802	-0.869	0.075	-0.072	0.779	-0.689
	Lecture-Reisslein	-0.003	-0.085	0.948	-0.868	0.254	-0.258	0.890	-0.826
QCIF	*Citizen Kane*	-0.083	0.223	0.173	-0.077	0.191	-0.149	0.760	-0.571
R.C.	*Die Hard I*	-0.187	0.380	0.151	-0.090	0.213	-0.185	0.653	-0.593
64 kbps	*Jurassic Park I*	-0.145	0.271	0.181	-0.107	0.332	-0.294	0.776	-0.624

Table 17: *continued*

		Base Layer				Aggregate Stream			
		Frame Level		GoP level		Frame Level		GoP level	
Enc. M.	Video	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$	ρ_{XM}	ρ_{XQ}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$
	Silence of the Lambs	-0.128	0.276	0.223	-0.100	0.245	-0.154	0.792	-0.556
	Star Wars IV	-0.125	0.325	0.170	-0.131	0.108	-0.122	0.625	-0.505
	Star Wars V	-0.131	0.289	0.096	-0.056	0.334	-0.257	0.798	-0.571
	The Firm	-0.116	0.249	0.202	-0.131	0.260	-0.217	0.779	-0.665
	Terminator I	-0.160	0.365	0.180	-0.145	0.232	-0.295	0.696	-0.662
	Total Recall	-0.153	0.331	0.163	-0.112	0.223	-0.219	0.686	-0.641
	Aladdin	-0.181	0.333	0.385	-0.346	0.271	-0.341	0.735	-0.715
	Cinderella	-0.168	0.345	0.291	-0.182	0.275	-0.263	0.733	-0.657
	Baseball with Comm	-0.137	0.362	0.170	-0.147	0.223	-0.210	0.637	-0.566
	Snowboard with Comm	-0.203	0.421	0.282	-0.235	0.287	-0.336	0.723	-0.681
	Oprah w/o Comm	-0.135	0.300	0.212	-0.168	0.233	-0.233	0.760	-0.679
	Tonight Show w/o Comm	-0.113	0.054	0.202	-0.025	0.207	-0.142	0.594	-0.342
	Lecture-Gupta	-0.099	0.249	0.313	-0.180	0.127	-0.105	0.889	-0.769
	Lecture-Reisslein	-0.135	0.100	0.241	-0.085	0.329	-0.333	0.892	-0.
QCIF R.C. 128 kbps	*Citizen Kane*	-0.102	0.355	0.074	-0.036	0.012	0.086	0.702	-0.456
	Die Hard I	-0.217	0.509	0.037	-0.018	-0.070	0.160	0.497	-0.407
	Jurassic Park I	-0.178	0.402	0.062	-0.038	0.090	-0.006	0.739	-0.510
	Silence of the Lambs	-0.158	0.416	0.054	-0.033	0.029	0.118	0.752	-0.453
	Star Wars IV	-0.148	0.465	0.080	-0.062	-0.023	0.168	0.618	-0.404
	Star Wars V	-0.160	0.426	0.037	-0.003	0.057	0.030	0.722	-0.470
	The Firm	-0.142	0.380	0.116	-0.093	0.022	0.080	0.705	-0.550
	Terminator I	-0.188	0.499	0.039	-0.016	0.045	0.029	0.629	-0.528
	Total Recall	-0.181	0.467	0.056	-0.051	-0.034	0.119	0.516	-0.458
	Aladdin	-0.214	0.471	0.123	-0.064	0.150	-0.103	0.745	-0.675
	Cinderella	-0.200	0.466	0.124	-0.056	0.065	0.029	0.722	-0.581
	Baseball with Comm	-0.163	0.507	0.045	-0.031	-0.038	0.119	0.486	-0.380
	Snowboard with Comm	-0.236	0.547	0.062	-0.022	0.142	-0.062	0.701	-0.591
	Oprah w/o Comm	-0.176	0.444	0.094	-0.069	0.034	0.011	0.796	-0.705
	Tonight Show w/o Comm	-0.144	0.114	0.098	-0.015	0.011	0.020	0.416	0.008
	Lecture-Gupta	-0.145	0.488	0.205	-0.065	-0.071	0.191	0.878	-0.741
	Lecture-Reisslein	-0.238	0.243	0.061	-0.005	0.077	-0.046	0.840	-0.534
QCIF R.C. 256 kbps	*Citizen Kane*	-0.121	0.516	0.012	-0.003	-0.192	0.360	0.606	-0.431
	Die Hard I	-0.245	0.636	-0.014	0.023	-0.414	0.545	0.419	-0.346
	Jurassic Park I	-0.210	0.554	0.021	-0.008	-0.165	0.304	0.710	-0.479
	Silence of the Lambs	-0.184	0.571	0.001	-0.002	-0.189	0.440	0.682	-0.409
	Star Wars IV	-0.167	0.604	0.008	-0.005	-0.301	0.490	0.511	-0.339
	Star Wars V	-0.183	0.572	0.024	0.001	-0.243	0.297	0.575	-0.371
	The Firm	-0.168	0.540	0.041	-0.015	-0.226	0.406	0.611	-0.478
	Terminator I	-0.213	0.626	-0.000	0.016	-0.264	0.376	0.573	-0.479
	Total Recall	-0.206	0.606	0.009	-0.005	-0.348	0.487	0.448	-0.405
	Aladdin	-0.245	0.607	0.035	-0.006	-0.197	0.344	0.670	-0.583
	Cinderella	-0.228	0.591	0.020	0.010	-0.215	0.396	0.708	-0.570
	Baseball with Comm	-0.184	0.648	0.016	0.004	-0.419	0.507	0.375	-0.269
	Snowboard with Comm	-0.270	0.682	0.047	-0.006	-0.234	0.350	0.600	-0.488
	Oprah w/o Comm	-0.220	0.606	0.026	-0.010	-0.319	0.366	0.806	-0.747
	Tonight Show w/o Comm	-0.173	0.216	0.073	-0.011	-0.156	0.079	0.416	0.047
	Lecture-Gupta	-0.198	0.751	0.163	-0.051	-0.488	0.632	0.681	-0.540
	Lecture-Reisslein	-0.330	0.451	0.029	-0.000	-0.322	0.239	0.632	-0.352

Figures 34 and 35 give scatter plots of the tuples $(X_n,\ Q_n)$ and $(X_n^{(12)},\ Q_n^{(12)})$, respectively.

Figure 36 gives the rate-distortion plots, i.e., the average video quality $(\bar{Q})$ as a function of the average frame size $(\bar{X})$. The plots are obtained from the five different quality level encodings of the videos.

5 Discussion

As we have observed in the preceding sections, for the encodings without rate control, aggregating the base and enhancement layers gives video streams that are equivalent to the corresponding single layer stream studied in Part 2. In extensive numerical investigations, not detailed here due to space constraints, we have also verified that extracting the I and P frames out of a single layer encoding is equivalent to the base layer of a temporal scalable encoding. Extracting the B frames out of a single layer encoding gives a stream equivalent to the enhancement layer of a temporal scalable encoding. This is to be expected as temporal scalable encoding adds essentially no overhead.

Note that the above holds only for the encodings without rate control (i.e., when the quantization parameters are fixed for the entire duration of a given video). If rate control is employed for the base layer encoding, the obtained base layer is very different from the I and P frame sequence of a single layer encoding — both if it is done with or without rate control. Similarly, the enhancement layer obtained from an actual temporal scalable encoding with a rate-controlled base layer is quite different from the B frame sequence of a single layer encoding, even though the enhancement layer of the temporal scalable encoding is coded with fixed quantization parameters. In particular, the higher the base layer (target) bit rate, the lower the average enhancement layer bit rate. This is intuitive since the more information is accommodated in the base layer, the smaller the amount of information left over for the enhancement layer.

6 Conclusion

Our traces of temporal scalable encoded videos with rate control for the base layer provide realistic traffic data for evaluating the widely advocated networking scenario with a (nearly) constant bit rate base layer and a variable bit rate enhancement layer. The widely used TM5 rate control mechanism, which we also employed in our encodings, tries to stabilize the bit rate at the GoP time scale (while the bit rate at the frame time scale is quite variable). We therefore recommend to employ our traces in scenarios were the video traffic is smoothed over the individual frames in a GoP (which incurs a delay of only about 0.4 sec) or using some other smoothing algorithm.

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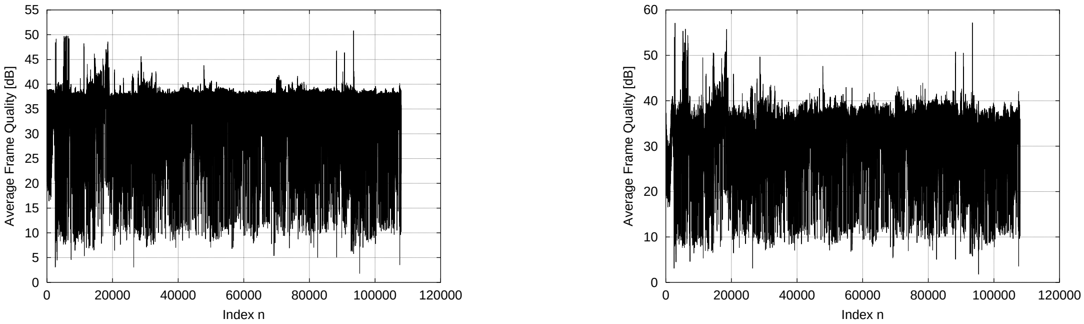
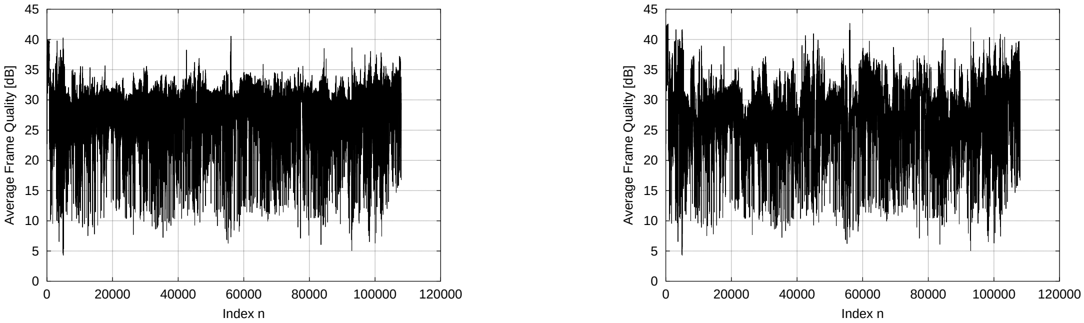
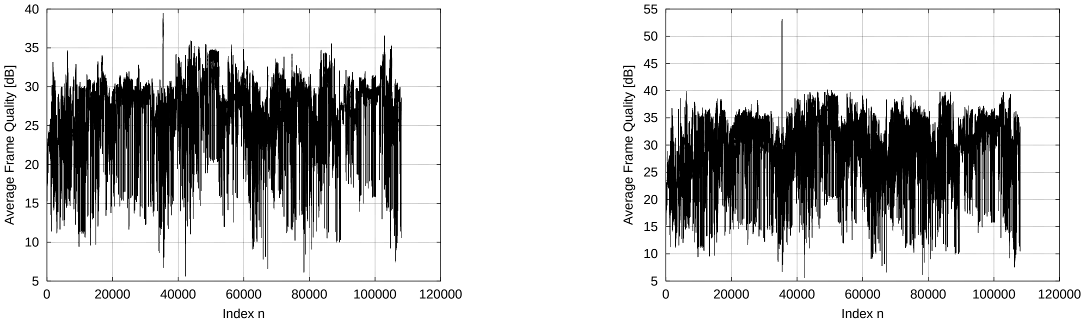


a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



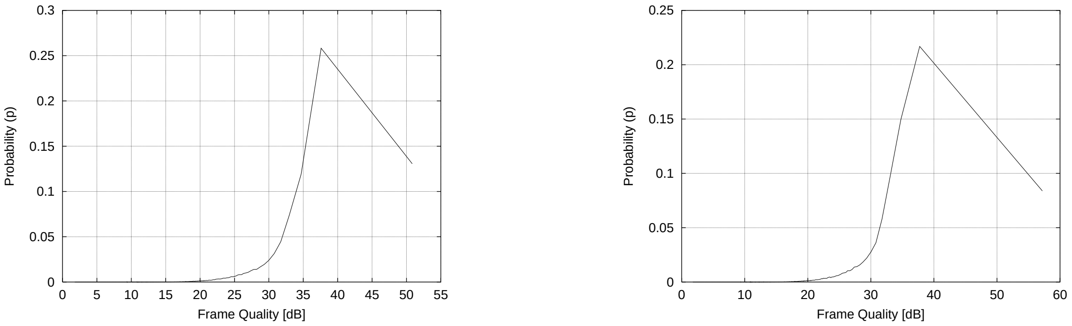
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

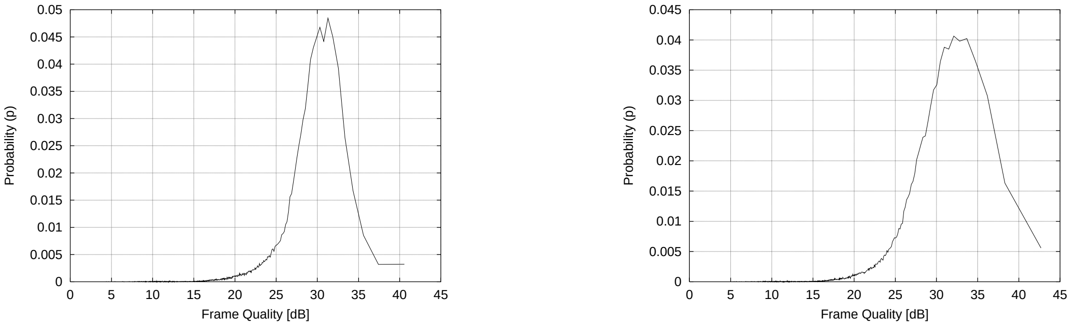
Encoding without rate control Encoding with rate control

Figure 26: Video frame quality Q_n^b (in dB) as a function of the frame index n for the base layer of temporal scalable QCIF video.



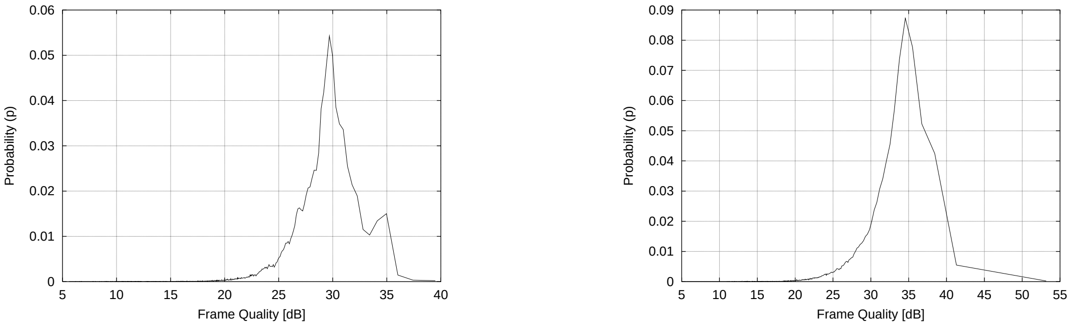
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



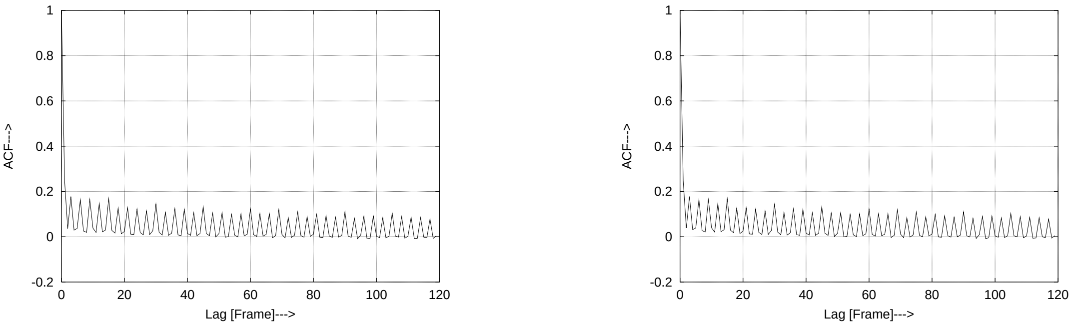
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

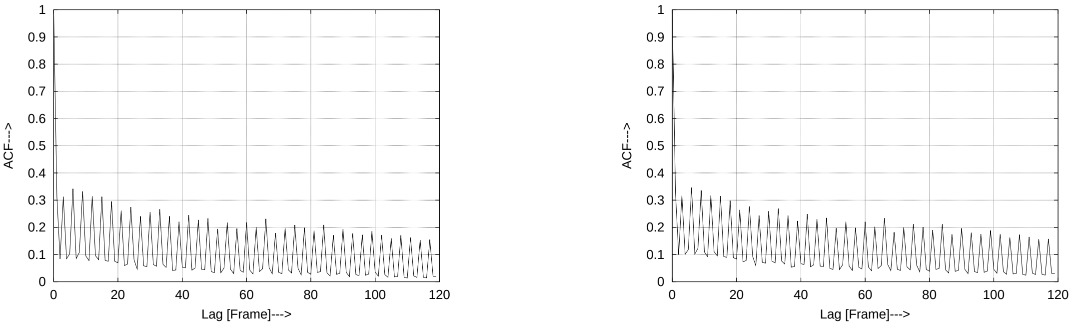
Encoding without rate control

Encoding with rate control

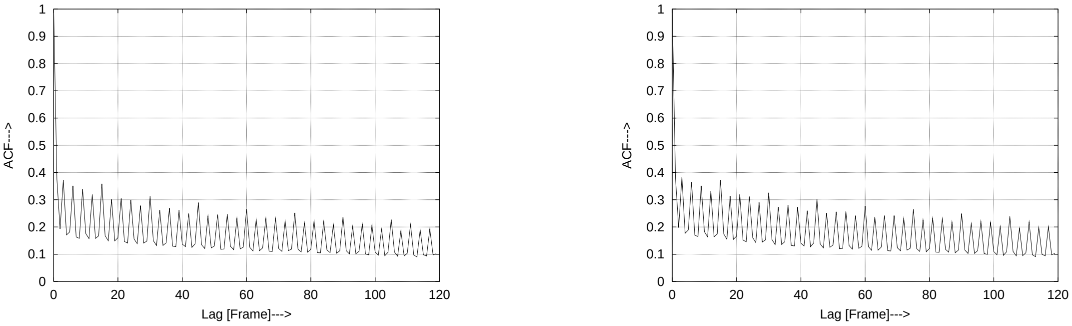
Figure 27: Histograms of video frame quality Q_n^b (in dB) of the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



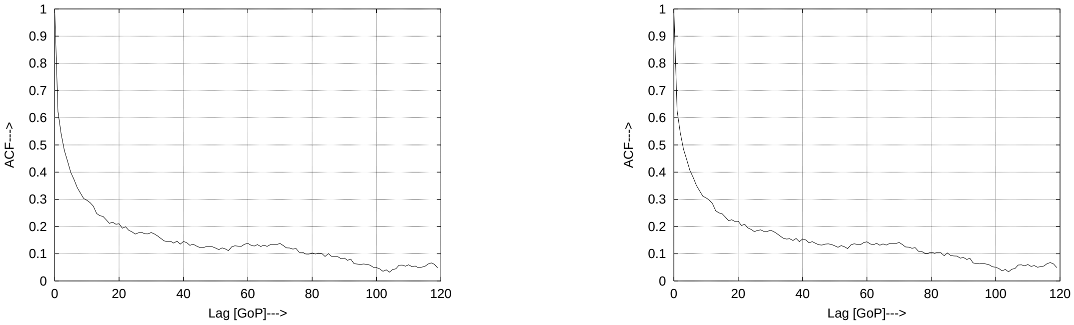
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

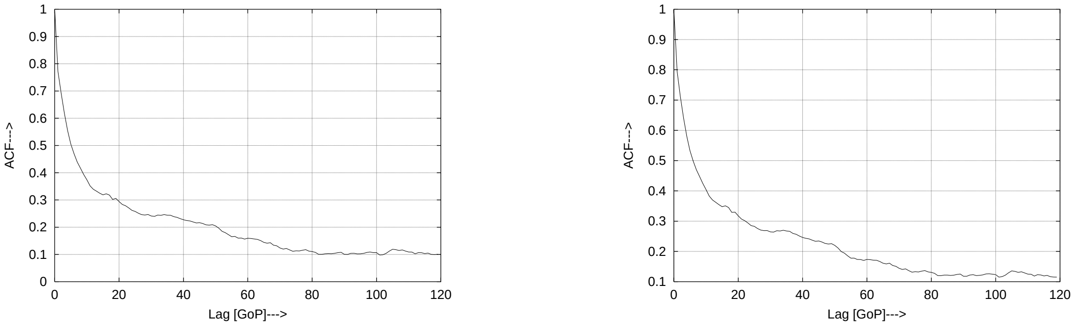
Encoding without rate control Encoding with rate control

Figure 28: MSE autocorrelation coefficient $\rho_M(k)$ as as function of the lag k (in frames) for the base layer of temporal scalable QCIF video.



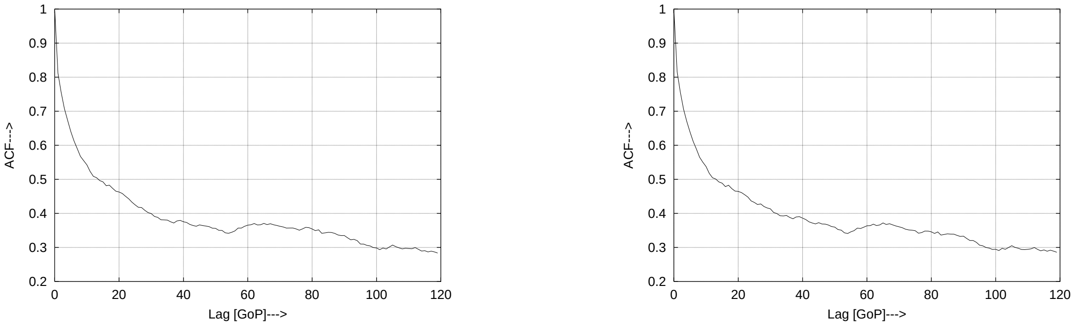
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



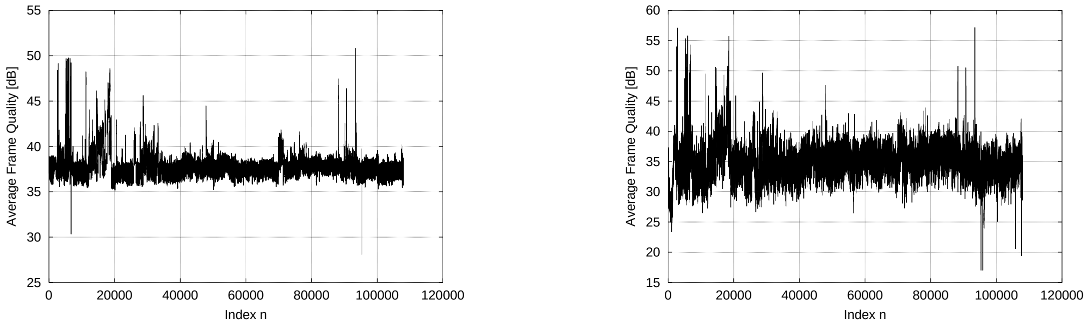
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

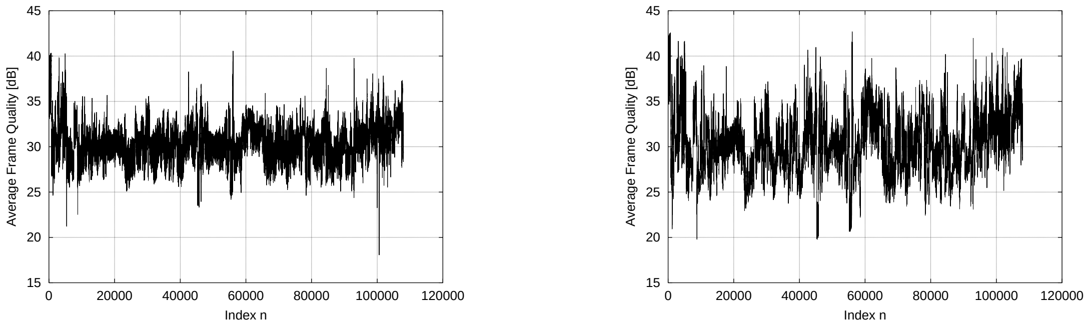
Encoding without rate control

Encoding with rate control

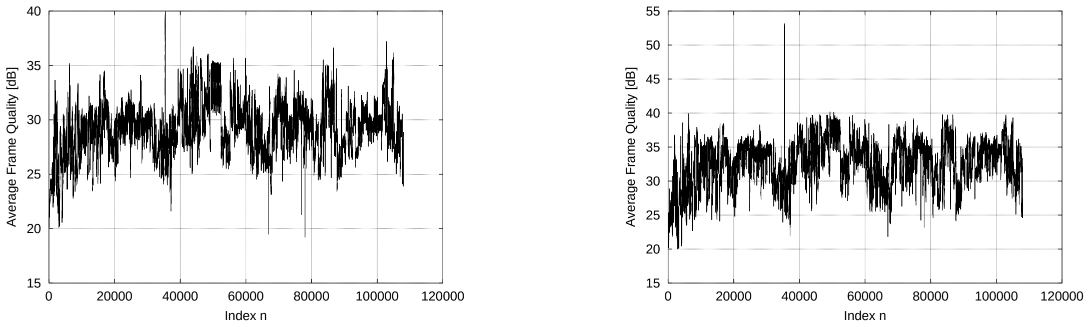
Figure 29: MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of the lag k (in GoPs) for the base layer of temporal scalable QCIF video.



a) *Star Wars IV* with high quality　　d) *Star Wars IV* with 256 kbps target bit rate



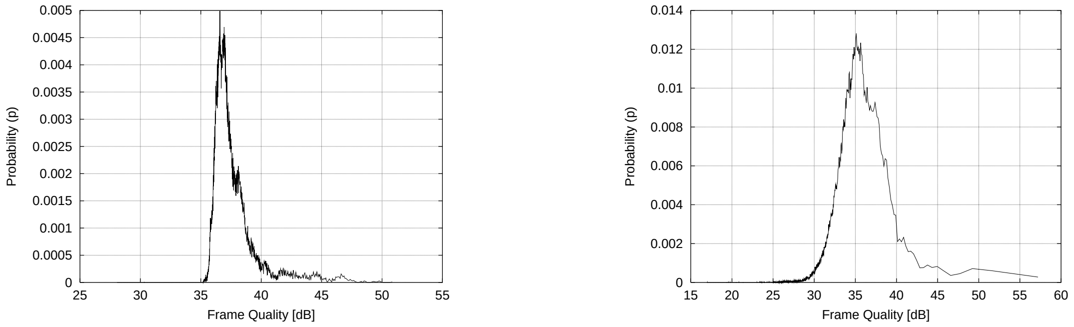
b) *Jurassic Park I* with medium quality　　e) *Jurassic Park I* with 128 kbps target bit rate



c) *Silence of the Lambs* with low quality　　f) *Silence of the Lambs* with 64 kbps target bit rate

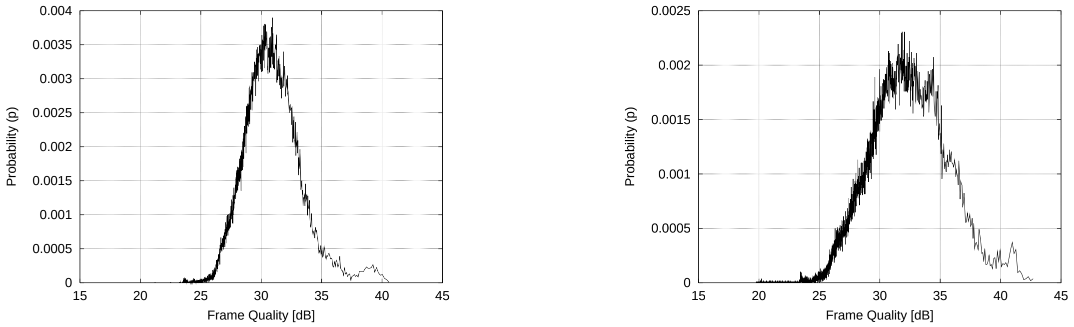
Encoding without rate control　　Encoding with rate control

Figure 30: Video frame quality Q_n^{agg} (in dB) as a function of the frame index n for the aggregate stream of temporal scalable QCIF video.



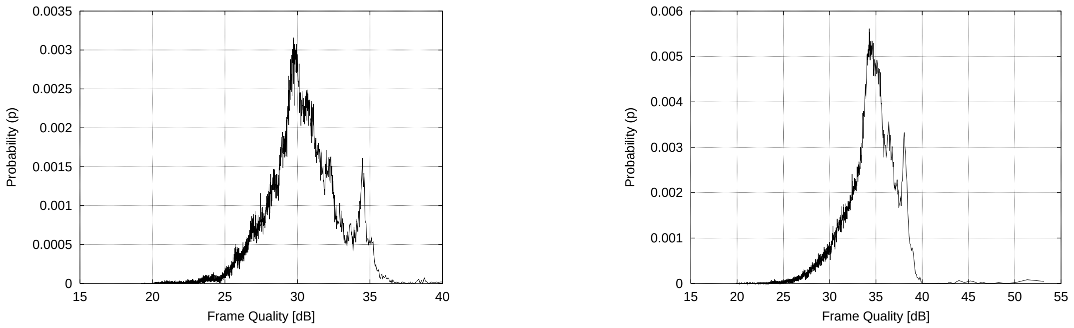
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



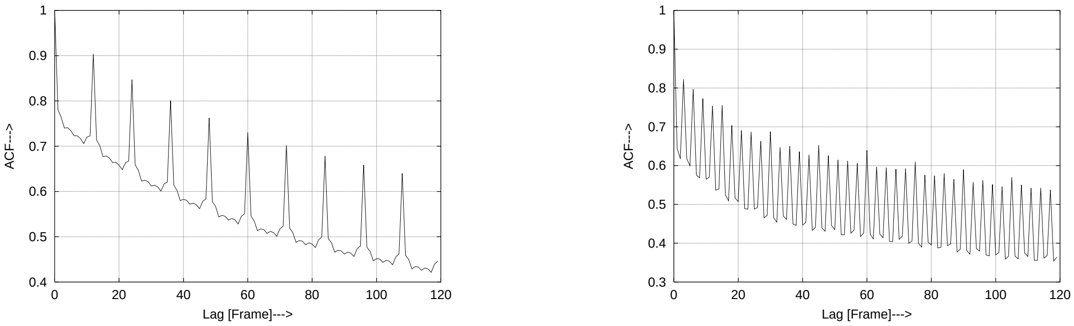
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control

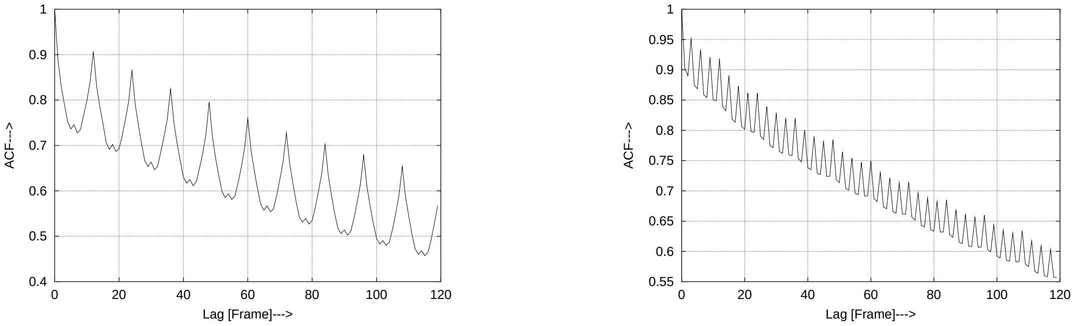
Encoding with rate control

Figure 31: Histograms of video frame quality Q_n^{agg} (in dB) of the aggregate stream of temporal scalable QCIF video.



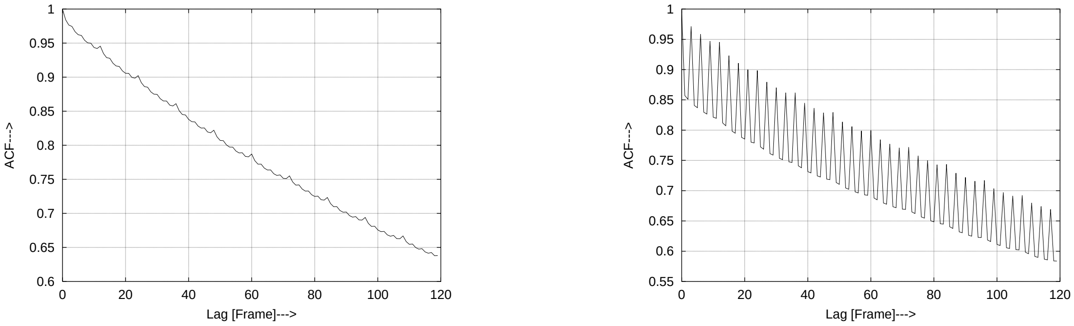
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



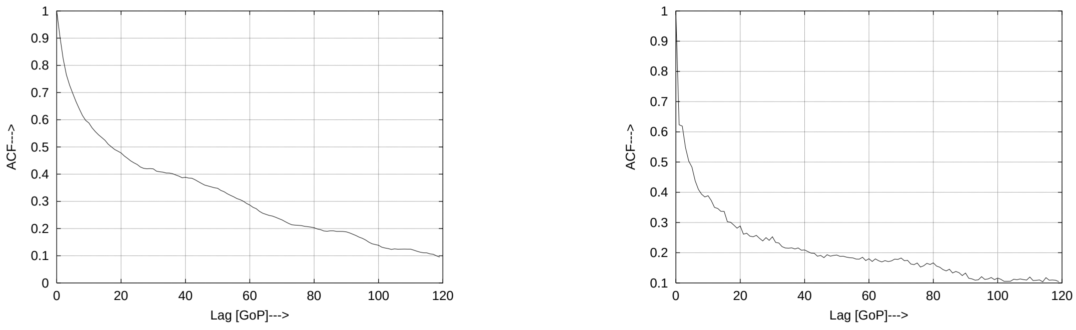
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control

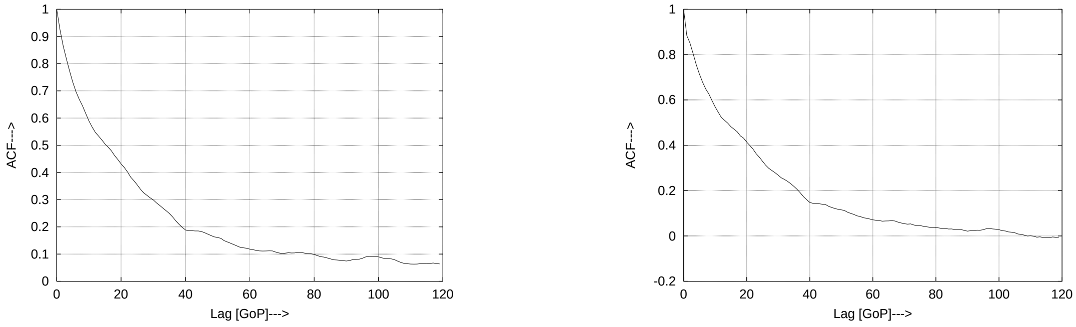
Encoding with rate control

Figure 32: MSE autocorrelation coefficient $\rho_M(k)$ as as function of the lag k (in frames) for the aggregate stream of temporal scalable QCIF video.



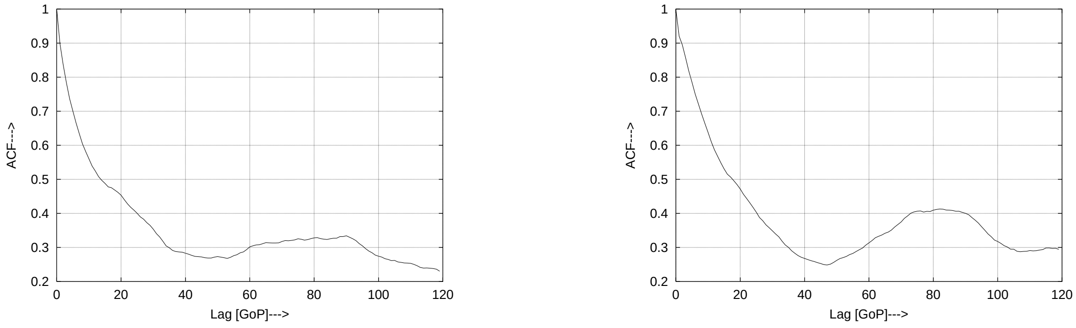
a) *Star Wars IV* with high quality

d) *Star Wars IV* with 256 kbps target bit rate



b) *Jurassic Park I* with medium quality

e) *Jurassic Park I* with 128 kbps target bit rate



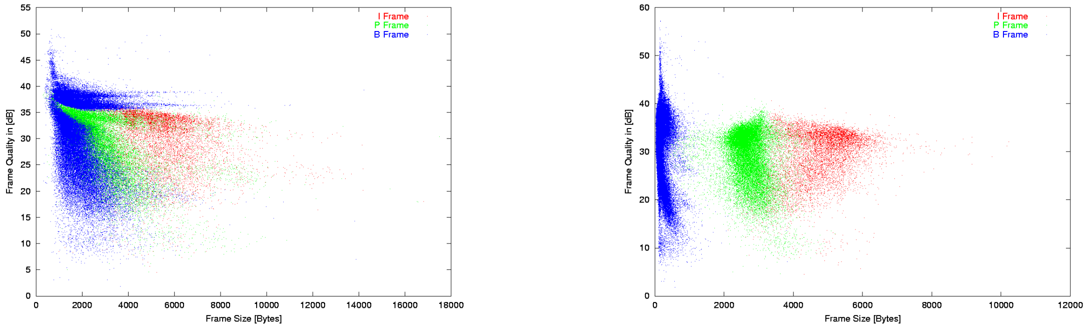
c) *Silence of the Lambs* with low quality

f) *Silence of the Lambs* with 64 kbps target bit rate

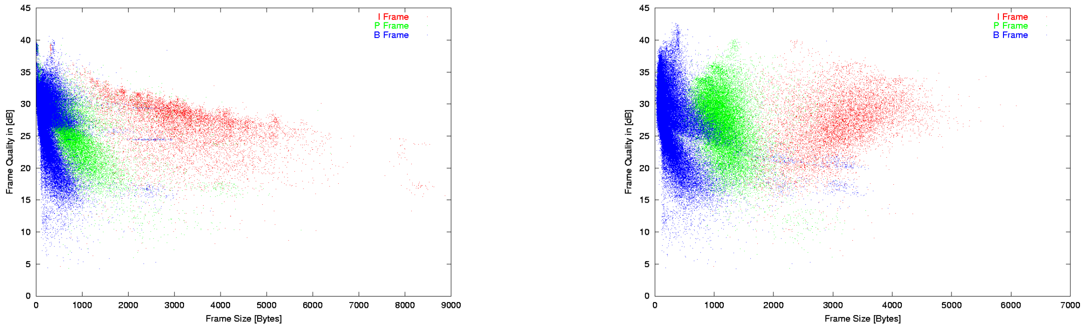
Encoding without rate control

Encoding with rate control

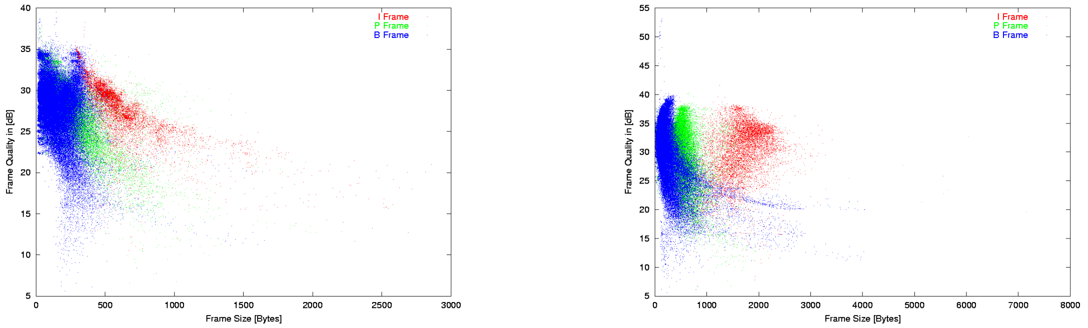
Figure 33: MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of the lag k (in GoPs) for the aggregate stream of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



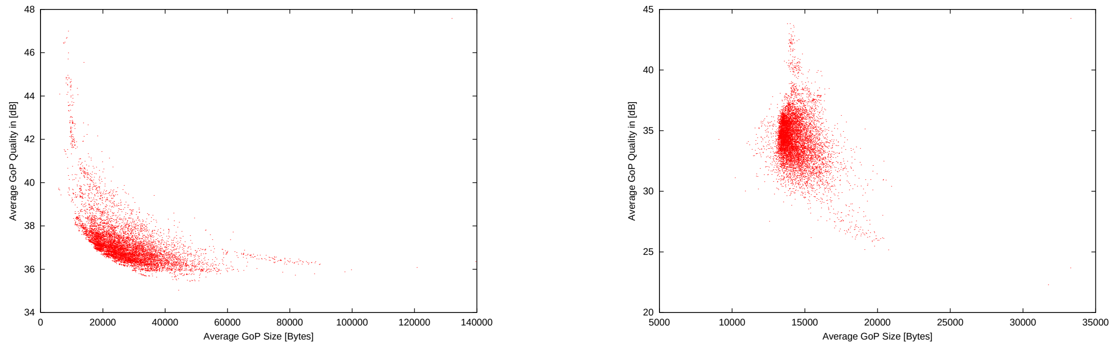
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



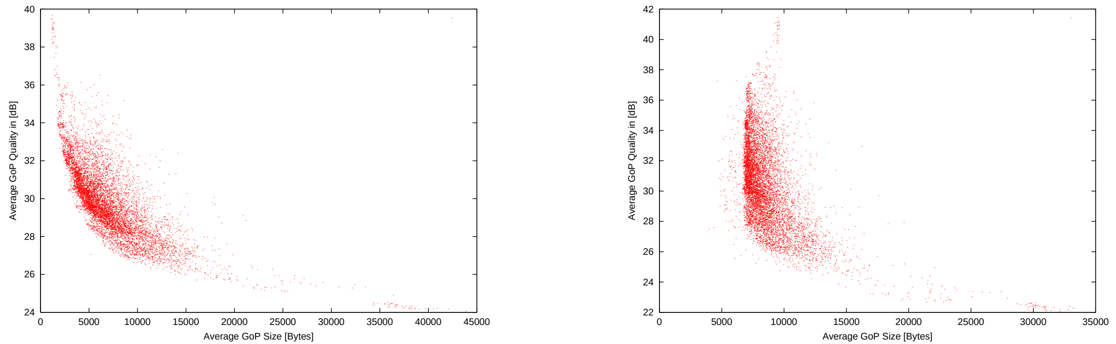
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

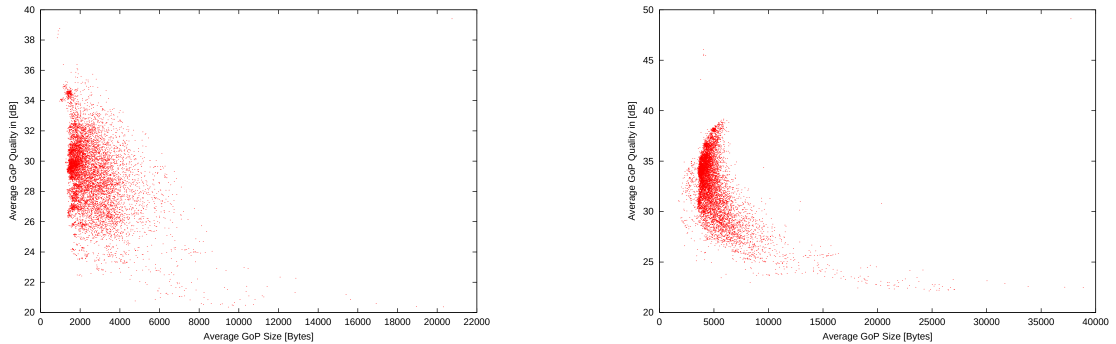
Figure 34: Scatter plots of frame size and frame quality for aggregate stream of temporal scalable QCIF video.



a) *Star Wars IV* with high quality d) *Star Wars IV* with 256 kbps target bit rate



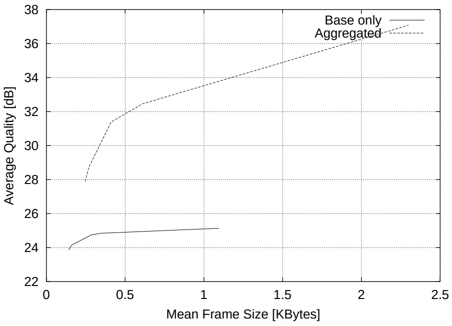
b) *Jurassic Park I* with medium quality e) *Jurassic Park I* with 128 kbps target bit rate



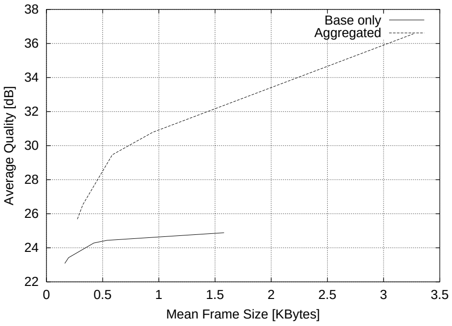
c) *Silence of the Lambs* with low quality f) *Silence of the Lambs* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

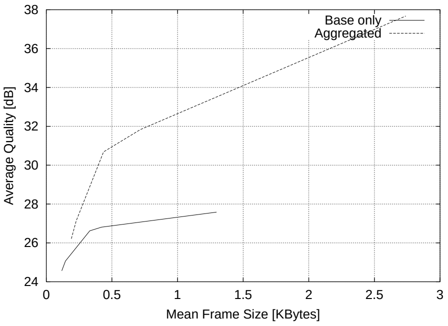
Figure 35: Scatter plots of GoP size and average GoP quality for aggregate stream of temporal scalable QCIF video.



a) *Star Wars IV*



b) *Jurassic Park I*



c) *Tonight show w/o Commercials*

Figure 36: Rate–distortion plots for aggregate stream of temporal scalable QCIF video.