Traffic and Quality Characterization of Scalable Encoded Video: A Large-Scale Trace-Based Study

Part 4: Statistical Analysis of Spatial Scalable Encoded Video *[†]

Martin Reisslein[‡] Jeremy Lassetter Sampath Ratnam Osama Lotfallah
Frank H.P. Fitzek[§] Sethuraman Panchanathan

December 1, 2003

Abstract

In this part we study the traffic and quality characteristics of spatial scalable encoded videos. Six video sequences representing different genres were spatially encoded into two layers, the base layer, and the enhancement layer. Each sequences are of CIF type and 30 minutes in length. We studied the traffic and quality characteristics of base layer (QCIF), the enhancement layer (traffic only) and the aggregated layer (base + enhancement layer). A 12 frame GoP was chosen for base layer and enhancement layer, such that spatial layer GoP matches with that of single layer encodings. Our encodings with rate control have a rate-controlled base layer, while the corresponding 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. Our statistical analysis provides an insights into these layer streams and there behavior when compared to the corresponding single layer encodings. Our traffic studies shows a double "hump" in coefficient of variation and peak–to–mean ratio for both base layer traffic and the aggregated layer traffic. These peaks are centered at quantization parameter corresponding to 060810 and 101416. In most of the cases, the Hurst parameter estimated from the R/S plot, the periodogram, and the variance time plot are the same for the base layer traffic and the enhancement layer traffic. This indicates that long range dependence is not changed by scaling the input video sequence.

1 Introduction

In this part we conduct a statistical analysis of the video traffic and the video quality for the spatial scalable encoded video. This statistical analysis is based on the terse traces of the base

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*Supported in part by the National Science Foundation under Grant No. Career ANI-0133252 and Grant No. ANI-0136774. Supported in part by the State of Arizona through the IT301 initiative.

[†] Please direct correspondence to M. Reisslein.

[‡] J. Lassetter, S. Ratnam and M. Reisslein are with the Dept. of Electrical Engineering, Arizona State University, Goldwater Center, MC 5706, Tempe AZ 85287–5706, Phone: (480)965–8593, Fax: (480)965–8325, (email: `{reisslein, jeremy.lassetter, sampath.ratnam, osama.lotfallah, panch}@asu.edu`, web: `http://trace.eas.asu.edu`).

[§] F. Fitzek is with acticom GmbH, Am Borsigturm 42, 13507 Berlin, Germany Phone: +49–30–4303–2510, Fax: +49–30–4303–2519, (email: `fitzek@acticom.de`, web: `http://www.acticom.de`).

layer and the corresponding enhancement layer. Recall from Part 1 that the terse traces give the frame sizes of the individual layers. In addition, the terse base layer trace gives 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 spatial 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. Recall that in the considered spatial scalable encodings, each frame has a base layer component and an enhancement layer component.

2.1 Base Layer Traffic

We give the compression ratios, the mean frame sizes ($\bar{X}^b$), the coefficients of variation (CoV_X^b), and the peak-to-mean ratios ($X_{\max}^b/\bar{X}^b$) in Table 1, along with the mean bit rates ($\bar{X}^b/T$), and the peak bit rates ($X_{\max}^b/T$).

It is interesting to note that the average size of a QCIF frame encoded without scalability or rate control is roughly the same size as a spatially scalable encoded frame from the base layer of the same movie in CIF format. From Table 1 of this report, as well as from Table 1 of Part 2, we observe that the relative order of the compression ratios achieved for video sequences at a given quality level is the same for both single layer encodings and encodings with spatial scalability.

The encoder used in this study was able to achieve the 128 kbps and 256 kbps target bit rates for the spatial encoding of a sequence with rate control, just as it did for single layer encodings with rate control. For a target bit rate of 64 kbps, the spatial encoder with rate control shows variations in the achieved bit rates. The encoder was able to achieve the target bit rate of 64 kbps for the *Silence of the Lambs* video sequence for both spatial and single layer encodings, whereas for the remaining three video sequences — *Terminator I*, *Snowboard with Commercials*, and *Oprah without Commercials* — the encoder achieved higher than the target 64 kbps bit rate for both the single layer and spatial encodings of the corresponding sequences in CIF format. Additionally, for these three video sequences, the bit rates achieved for a target of 64 kbps were nearly equal and have mean bitrate greater than 64kbps for the largest quantization parameter 30,30,30 when we compare single layer encodings with spatial base layer encodings.

The coefficient of variation of a single layer encoded video sequence does not appear to have a consistent relationship with the coefficient of variation of the video sequence encoded with spatial scalability. Sometimes the CoV_X^b is larger for a spatially encoded video sequence than the single layer encoding, and sometimes the CoV_X^b is larger for a single layer encoding than the video encoded with spatial scalability, although the values for the two for encodings with and without scalability are very close to one another.

When interpreting the statistics given in various tables, keep in mind that the base layer of the studied spatial scalable encoding provides the video in the QCIF format. Single layer video in the QCIF format is studied in Part 2 of this technical report. We will therefore now compare the base layer statistics here with the single layer QCIF statistics from Part 2.

We observe that the compression ratio of the base layer video is about four times larger than the compression ratios of the single layer QCIF video in Table 1 of Part 2. This is to be expected as the QCIF format has half the number of pixels as the CIF format in both the horizontal and the vertical direction. Taking a closer look at the average base layer frame size ($\bar{X}^b$) of the encodings without rate control in comparison with the corresponding average single layer QCIF frame sizes ($\bar{X}$) in Table 1 of Part 2, we observe the following.

For the high quality encodings without rate control, the $\bar{X}^b$ values of *Terminator I*, *Snowboard with Commercials*, and *Oprah without Commercials* are between 4% and 6% larger than the $\bar{X}$ values . For the medium quality, the $\bar{X}^b$ values are between 1% and 4% larger. The $\bar{X}^b$ of the high and medium quality of *Silence of the Lambs*, on the other hand, are about the same as $\bar{X}$. For the low quality encodings of *Snowboard with comm* and *Oprah w/o comm* the $\bar{X}^b$ are between 0.5% to 2% smaller than the corresponding $\bar{X}$. For *Silence of the Lambs* and *Terminator I*, $\bar{X}^b$ is nearly 1% to 4% higher than $\bar{X}$ for various quality levels.

Next, we notice that for the encodings without rate control, the behavior of the traffic variability measured in CoV_X^b and $X_{\max}^b/\bar{X}^b$ compared to CoV_X and $X_{\max}/\bar{X}$ in Table 1 of Part 2 is complementary to the behavior of the mean frame size ($\bar{X}^b$). Specifically, while the values appear to be very close, the encodings without rate control of *Terminator I*, *Snowboard with Commercials*, and *Oprah without Commercials* have usually smaller CoV_X^b and $X_{\max}^b/\bar{X}^b$ compared to CoV_X and $X_{\max}/\bar{X}$ of the corresponding single layer QCIF encodings. For *Silence of the Lambs* we do not find a consistent behavior for non-rate controlled encodings.

For encodings with rate control we observe again that the TM5 rate control matches the target bit rates of 128 kbps and 256 kbps while having problems meeting the 64 kbps target bit rate. There appears to be no clear general trend in the behavior of the variability of the base layer encodings with rate control in comparison with the variability of the corresponding single-layer QCIF encodings. Only for the 128 kbps encodings, there is a clear trend in that the base layer encodings have smaller CoV_X^b and $X_{\max}^b/\bar{X}^b$. For the other quality levels we observe conflicting trends in CoV_X^b and $X_{\max}^b/\bar{X}^b$. For the 256 kbps encodings for instance, CoV_X^b is smaller than CoV_X, while there is no clear trend in the behavior of $X_{\max}^b/\bar{X}^b$ with respect to $X_{\max}/\bar{X}$.

Considering the base layer traffic for the different quality levels without rate control, we observe a double "hump" behavior of first increasing and then decreasing variability as the quality level decreases. The first hump is observed at 060810 and the second hump at M.Q.

Table 2 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.

We observe that the $Y_{\max}^b/\bar{Y}^b$ and $Y_{\max}^b/(GT)$ values for the base layer encodings without rate control are consistently smaller than the $Y_{\max}/\bar{Y}$ and $Y_{\max}/(GT)$ values in Table 2 of Part 2. On the other hand, there appears to be no clear trend in the correlation of the behavior of CoV_Y^b in comparison with the corresponding single layer CoV_Y.

For the encodings without rate control, we observe that $Y_{\max}^b/\bar{Y}^b$ is largest for medium quality (quantization parameter ranging from 101010 to 101416) than any other quality encoded video. CoV_Y^b is largest for the H.M quality level encoded videos when compared with other encodings with and without rate control. The behavior of $Y_{\max}^b/\bar{Y}^b$ and CoV_Y^b is the same as was observed earlier several times i.e., we find a "hump" where the peak is centered around the medium quality encoding. The variability of the GoP size for the medium quality traces is greater than the variability of the GoP size for both the high and low quality traces. This observation can also be made from Figure 4, which shows the GoP size histograms. The medium quality encoding of *Snowboard with Commercials* has a much wider histogram, than either of the two histogram plots of the high quality *Silence of the Lambs*, or the low quality *Oprah without Commercials*.

For the rate-controlled sequences, $Y_{\max}^b/\bar{Y}^b$ are largest for videos encoded with 64 kbps and 128 kbps target bits when compared to 256 kbps target bit rate encoded videos. However the peak-to-mean ratios do not exhibit a consistent relationship when compared for the 64 kbps and 128 kbps target bit rates. We observe that CoV_Y^b are largest for the encodings with a target bit rate of 64 kbps, followed by 128 kbps, and have the smallest values for the sequences with a target bit rate of 256 kbps. These values imply that the encodings with a target bit rate of 64 kbps have more GoP size variability than encodings with a target bit rate of 128 kbps, which in turn have more GoP size variability than encodings with a target bit rate of 256 kbps. This can also be observed in Figure 4, which, as was mentioned above, gives the GoP size histograms. While it is difficult to observe the difference in the variability of the 128 kbps and 256 kbps encodings of *Snowboard with Commercials* and *Silence of the Lambs* — they both appear to be very sharp — the 64 kbps encoding of *Oprah without Commercials* has a much duller peak than these other two histograms. Also, we observe that the 128 kbps and 256 kbps base layer encodings have typically somewhat smaller peak-to-mean ratios and peak bit rates than the corresponding single layer encodings.

The GoP level peak-to-mean ratio ($Y_{\max}/\bar{Y}$) and the coefficient of variation (CoV_Y^b) of spatially scalable encoded CIF video sequences decreases because as the aggregation level increases, the encoded frame sizes traffic becomes more smooth. We observe that for a given video, the mean GoP size of the base layer of the spatial encoding is nearly equal to the mean GoP size of the single layer encoding (QCIF).

The effect of the source video quality can have a severe impact on the compression ratios as is observed with *LectureHQ-Reisslein*. The poorer the source sequence video quality, the smaller the compression ratio achieved for the same quality encoding. This ratio can vary from 3 for high quality encoding to nearly 2 for low quality encoding. This is due to the fact that the existing compression algorithms try to exploit the high degree of correlation in neighboring pixels. Noisy video sequences tend to have small correlation of neighboring pixels, thus severely effecting the compression ratios. The coefficient of variation is smaller for the base layer of the spatial encoded video when compared with the single layer encoded video (QCIF). However, we do not observe any consistent trend in peak-to-mean ratios. The peak bit rates of spatially encoded CIF video sequences are smaller than the peak bit rates of the single layer encodings of QCIF video sequences. This difference can range anywhere from zero to around 600 kbps.

The CoV_X^b decreases for all spatially encoded CIF video sequences at the target bit rates of 128 kbps and 256 kbps when compared to the single layer encoded QCIF video sequences. For other encoding modes, the CoV_X^b has no consistent relation between single layer and spatial scalable encodings. The peak-to-mean ratio is smaller in the spatial encodings than for the single layer encodings at the GoP level for almost all video sequences as well as for all the encoding modes.

Table 1: Overview of frame statistics of the base layer of spatial 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]
CIF	*Silence of the Lambs*	81.406	1.868	0.831	8.849	0.448	3.967
H.Q.	*Terminator One*	48.922	3.108	0.599	4.780	0.746	3.566
No R.C.	*Snowboard with Comm*	31.018	4.902	0.463	4.647	1.177	5.468
	Oprah w/o Comm	25.965	5.857	0.343	2.841	1.406	3.994
	LectureHQ-Reisslein	72.205	2.106	0.712	6.719	0.505	3.396
	ParkingLot	25.507	5.962	0.541	3.167	1.431	4.532
CIF	*Silence of the Lambs*	173.185	0.878	1.588	16.427	0.211	3.462
040608.Q.	*Terminator One*	95.226	1.597	1.107	8.353	0.383	3.201
No R.C.	*Snowboard with Comm*	63.441	2.397	0.957	6.524	0.575	3.753

Table 1: *continued*

	Oprah w/o Comm	57.657	2.637	0.913	5.413	0.633	3.426
	LectureHQ-Reisslein	147.682	1.030	1.694	13.743	0.247	3.396
	ParkingLot	48.921	3.108	1.047	4.784	0.746	3.569
CIF 060810.Q. No R.C.	*Silence of the Lambs*	258.342	0.589	1.630	18.917	0.141	2.672
	Terminator One	134.163	1.133	1.110	8.915	0.272	2.425
	Snowboard with Comm	92.221	1.649	0.997	7.371	0.396	2.917
	Oprah w/o Comm	89.636	1.696	0.994	6.362	0.407	2.590
	LectureHQ-Reisslein	212.755	0.715	1.811	15.411	0.172	2.644
	ParkingLot	68.166	2.231	1.115	5.137	0.535	2.750
CIF H.M.Q. No.R.C.	*Silence of the Lambs*	307.831	0.494	1.316	15.602	0.119	1.850
	Terminator One	154.494	0.984	0.841	7.071	0.236	1.670
	Snowboard with Comm	108.287	1.404	0.782	7.376	0.337	2.486
	Oprah w/o Comm	111.503	1.364	0.688	5.417	0.327	1.773
	LectureHQ-Reisslein	250.216	0.608	1.390	12.795	0.146	1.866
	ParkingLot	77.709	1.957	0.893	4.523	0.470	2.124
CIF M.Q. No.R.C.	*Silence of the Lambs*	450.352	0.338	1.691	22.825	0.081	1.850
	Terminator One	237.519	0.640	1.219	10.468	0.154	1.608
	Snowboard with Comm	177.590	0.856	1.216	9.896	0.206	2.034
	Oprah w/o Comm	198.863	0.765	1.318	9.411	0.184	1.727
	LectureHQ-Reisslein	375.065	0.405	2.183	19.179	0.097	1.866
	ParkingLot	127.185	1.196	1.397	6.620	0.287	1.900
CIF M.L.Q. No.R.C.	*Silence of the Lambs*	652.895	0.233	1.076	14.778	0.056	0.826
	Terminator One	386.732	0.393	0.859	7.508	0.094	0.708
	Snowboard with Comm	314.815	0.483	0.939	7.913	0.116	0.917
	Oprah w/o Comm	416.413	0.365	0.953	8.037	0.088	0.704
	LectureHQ-Reisslein	651.441	0.233	1.615	15.354	0.056	0.860
	ParkingLot	248.430	0.612	1.206	5.702	0.147	0.838
CIF L.Q. No.R.C.	*Silence of the Lambs*	697.834	0.218	0.905	12.156	0.052	0.636
	Terminator One	450.956	0.337	0.786	6.833	0.081	0.553
	Snowboard with Comm	389.689	0.390	0.896	7.660	0.094	0.717
	Oprah w/o Comm	546.299	0.278	0.945	7.943	0.067	0.531
	LectureHQ-Reisslein	755.253	0.201	1.423	13.817	0.048	0.668
	ParkingLot	330.117	0.461	1.213	5.922	0.111	0.655
CIF 64 kbps R.C.	*Silence of the Lambs*	560.939	0.271	1.156	32.089	0.065	2.088
	Terminator One	456.386	0.333	0.773	6.792	0.080	0.543
	Snowboard with Comm	397.668	0.382	0.883	12.077	0.092	1.108
	Oprah w/o Comm	544.739	0.279	0.920	17.883	0.067	1.198
	LectureHQ-Reisslein	568.990	0.267	2.107	22.267	0.064	1.428
	ParkingLot	340.570	0.446	1.200	5.888	0.107	0.631
CIF 128 kbps R.C.	*Silence of the Lambs*	284.834	0.534	1.092	16.238	0.128	2.081
	Terminator One	284.803	0.534	1.042	22.556	0.128	2.890
	Snowboard with Comm	284.821	0.534	1.087	20.429	0.128	2.618
	Oprah w/o Comm	284.817	0.534	1.210	13.641	0.128	1.748
	LectureHQ-Reisslein	284.829	0.534	1.772	11.533	0.128	1.478
	ParkingLot	284.399	0.535	1.549	46.579	0.128	5.977
CIF 256 kbps R.C.	*Silence of the Lambs*	142.492	1.067	0.890	9.256	0.256	2.371
	Terminator One	142.493	1.067	0.962	9.506	0.256	2.435
	Snowboard with Comm	142.497	1.067	0.979	11.730	0.256	3.004
	Oprah w/o Comm	142.491	1.067	0.987	7.547	0.256	1.933
	LectureHQ-Reisslein	142.492	1.067	1.283	10.025	0.256	2.568
	ParkingLot	142.490	1.067	1.494	14.739	0.256	3.775

Table 2: Overview of GoP statistics of the base layer of spatial scalable encoded video

		GoP Size			Bit Rate
		Mean	CoV	Peak/Mean	Peak
Enc. M.	Video	$\bar{Y}^b$ [kbyte]	CoV_Y^b	$Y_{\max}^b/\bar{Y}^b$	$Y_{\max}^b/(GT)$ [Mbps]
CIF	*Silence of the Lambs*	22.416	0.658	6.820	3.057
H.Q.	*Terminator One*	37.300	0.427	2.920	2.178
No.R.C.	*Snowboard with Comm*	58.828	0.369	2.691	3.166
	Oprah w/o Comm	70.279	0.258	1.899	2.669
	LectureHQ-Reisslein	25.272	0.245	2.780	1.405
	ParkingLot	71.541	0.408	2.348	3.360
CIF	*Silence of the Lambs*	10.537	0.777	9.078	1.913
040608.Q.	*Terminator One*	19.162	0.458	3.216	1.232
No R.C.	*Snowboard with Comm*	28.763	0.440	3.065	1.763
	Oprah w/o Comm	31.649	0.292	2.264	1.433
	LectureHQ-Reisslein	12.356	0.284	3.185	0.787
	ParkingLot	37.300	0.500	2.809	2.095
CIF	*Silence of the Lambs*	7.063	0.866	10.656	1.505
060810.Q.	*Terminator One*	13.601	0.478	3.371	0.917
No.R.C.	*Snowboard with Comm*	19.787	0.489	3.393	1.343
	Oprah w/o Comm	20.358	0.314	2.516	1.025
	LectureHQ-Reisslein	8.577	0.308	3.371	0.578
	ParkingLot	26.770	0.546	3.092	1.656
CIF	*Silence of the Lambs*	5.928	0.922	11.549	1.369
H.M.Q.	*Terminator One*	11.811	0.486	3.380	0.799
No.R.C.	*Snowboard with Comm*	16.851	0.521	3.624	1.221
	Oprah w/o Comm	16.365	0.333	2.706	0.886
	LectureHQ-Reisslein	7.293	0.322	3.456	0.504
	ParkingLot	23.482	0.565	3.197	1.501
CIF	*Silence of the Lambs*	4.052	0.819	11.032	0.894
M.Q.	*Terminator One*	7.683	0.455	3.279	0.504
No.R.C.	*Snowboard with Comm*	10.275	0.515	3.737	0.768
	Oprah w/o Comm	9.176	0.315	2.727	0.501
	LectureHQ-Reisslein	4.865	0.299	3.306	0.322
	ParkingLot	14.347	0.560	3.475	0.997
CIF	*Silence of the Lambs*	2.795	0.638	8.880	0.496
M.L.Q.	*Terminator One*	4.718	0.404	2.989	0.282
No.R.C.	*Snowboard with Comm*	5.796	0.470	3.608	0.418
	Oprah w/o Comm	4.382	0.327	2.910	0.255
	LectureHQ-Reisslein	2.801	0.252	3.163	0.177
	ParkingLot	7.345	0.584	3.840	0.564
CIF	*Silence of the Lambs*	2.615	0.523	7.032	0.368
L.Q.	*Terminator One*	4.046	0.370	2.753	0.223
No.R.C.	*Snowboard with Comm*	4.683	0.430	3.448	0.323
	Oprah w/o Comm	3.340	0.318	2.875	0.192
	LectureHQ-Reisslein	2.416	0.212	2.963	0.143
	ParkingLot	5.528	0.551	3.833	0.424
CIF	*Silence of the Lambs*	3.253	0.386	7.036	0.458
64 kbps	*Terminator One*	3.998	0.361	2.704	0.216
R.C.	*Snowboard with Comm*	4.589	0.421	3.392	0.311
	Oprah w/o Comm	3.350	0.300	4.575	0.307
	LectureHQ-Reisslein	3.207	0.144	3.785	0.243
	ParkingLot	5.358	0.545	3.813	0.409
CIF	*Silence of the Lambs*	6.406	0.116	4.754	0.609
128 kbps	*Terminator One*	6.407	0.159	3.562	0.456
R.C.	*Snowboard with Comm*	6.407	0.256	4.275	0.548
	Oprah w/o Comm	6.407	0.076	1.923	0.246
	LectureHQ-Reisslein	6.407	0.039	1.427	0.183
	ParkingLot	6.416	0.515	4.685	0.601
CIF	*Silence of the Lambs*	12.806	0.033	1.537	0.394
256 kbps	*Terminator One*	12.806	0.040	1.306	0.334
R.C.	*Snowboard with Comm*	12.806	0.054	1.481	0.379
	Oprah w/o Comm	12.806	0.022	1.213	0.311

Table 2: *continued*

LectureHQ-Reisslein	12.806	0.036	1.300	0.333
ParkingLot	12.806	0.081	2.410	0.617

Figure 1 gives frame sizes X_n^b (in bytes) as a function of the frame number n. We observe from these plots that the encodings without rate control generate highly variable frame sizes that are characteristic of open-loop video encodings. The encodings with rate control appear generally less variable. However, there are occasionally very large spikes in the frame sizes, which appear to be the reason for the relatively large CoV_X^b and $X_{\max}^b/\bar{X}^b$ observed in Table 1.

Figure 2 gives the GoP size Y_m^b (in bytes) as a function of the GoP number m. From Figure 2 we observe the variability of the GoP sizes that we described above.

Figure 3 gives the histograms of the frame sizes X_n^b. The histograms of the base layer frame sizes look fairly similar to the QCIF single layer frame size histograms in Figure 3 of Part 2, except for the absence of the second "bump" at large frame sizes in most of the base layer histograms.

The effectiveness of the rate control scheme employed in this investigation can be observed from the histogram plots shown in Figure 3. As the target bit rate increases from 64 kbps to 256 kbps, the histograms become narrower, and the peaks become sharper indicating that more frames are concentrated in a small range around the target bit rate. This range decreases as the target bit rate increases. This shows that as the target bit rate increases CoV_X^b decreases, as we have already observed. An ideal rate-controlled sequence would have a frame size histogram plot represented by an impulse at the target average frame size, which can be derived from desired target bit rate. From these histogram plots we observe that the high quality encoding of *Silence of the Lambs* has a broad distribution as well as a longer distribution tail than the low quality encoding of *Oprah without Commercials*, which has a narrower frame distribution and a shorter distribution tail.

It is interesting to note that *Oprah without Commercials* has different frame size distributions. All of the plots have multiple peaks meaning that the frame sizes are concentrated into multiple set of predominant ranges. This distinct set of frame sizes are clearly visible from the GoP size trace plots in Figure 2. The *Oprah without Commercials* GoP size plot shows a large number of rectangular regions, which look like small rectangular wells in the plot, and which correspond to a roughly constant frame size. This leads to multiple peaks in the histogram plot. The same phenomenon is observed in the histogram and frame size trace plots of the single layer encoding of *Lecture–Reisslein.* This behavior appears to be due to the video content, where both sequences have something in common i.e., in both there are only infrequent scene changes unlike in sports or commercials films.

Figure 5 gives the autocorrelation coefficient $\rho_X^b(k)$ of the frame size sequence X_n^b, $n = 0, \ldots, N-1$, as a function of the lag k (in frames). The large peaks, spaced 12 frames apart in these autocorrelation functions, are again due to the I-I/P-P correlations discussed in Part

1. The smaller peaks spaced 3 frames apart are due to the I-P/P-P frame size correlations. For the low quality and 64 kbps target bit rate these smaller peaks are not present. This is because the P and B frames tend to have the same sizes in these encodings.

The peaks in Figure 5 correspond to the large I frame sizes which are separated by a 12 frame period lag in the base layer. The autocorrelation function slope tends to be constant (roughly zero) for rate controlled video encoded sequences. This is because of nearly constant frame sizes in base layer. For our encodings rate control in applied only for base layer, enhancement layer for our encodings is non-rate controlled.

Figure 6 gives the autocorrelation coefficient $\rho_{Y^b}(k)$ of the GoP size sequence $Y^b_m,\ m = 0, \ldots, N/G-1$, as a function of the lag k (in GoPs). Remarkable is the large autocorrelation between 0.4 and 0.5 for lags up to 100 GoPs of the high quality *Silence of the Lambs* base layer. The autocorrelation coefficient for the base layer frame size trace at the GoP level decreases sharply for video sequences encoded at target bit rates of 256 kbps and 128 kbps. The autocorrelation drops to zero for lags of 20 GoPs. However, it takes lag periods of around 80 GoPs to bring the autocorrelation to nearly zero for target bit rate of 64 kbps. We find random fluctuations in the GoP level autocorrelation function for all rate controlled encoded sequences which is not observed in non-rate controlled encoded sequences. The same phenomenon was observed in single layer encoded sequences.

Table 3 gives the Hurst parameter determined with the R/S method (the first line of the given video and encoding mode) and the periodogram (the second line of the given video and encoding mode) for $X^b_n,\ n = 0, \ldots, N-1$, as a function of the aggregation level a.

Table 3: Hurst parameters estimated from pox diagram of R/S and periodogram as a function of the aggregation level a for base layer traffic.

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
CIF	*Silence of the Lambs*	0.916	0.898	0.897	0.927	0.968	0.927	0.959	0.825	0.870	0.897	0.836
H.Q.	*Silence of the Lambs*	1.211	1.241	1.160	1.051	1.114	1.135	1.049	1.141	1.053	1.024	1.183
No.R.C.	*Terminator One*	0.834	0.834	0.820	0.822	0.813	0.854	0.908	0.908	0.923	0.939	0.930
	Terminator One	1.158	1.108	1.031	0.938	0.935	0.772	0.822	0.761	0.715	0.800	0.752
	Snowboard with Comm	0.727	0.695	0.645	0.598	0.605	0.606	0.586	0.622	0.583	0.546	0.616
	Snowboard with Comm	1.192	1.087	0.820	0.805	0.791	0.678	0.539	0.556	0.617	0.564	0.463
	Oprah w/o Comm	0.878	0.856	0.840	0.843	0.850	0.878	0.836	0.807	0.904	0.724	0.817
	Oprah w/o Comm	1.217	1.242	1.222	1.127	1.095	1.008	1.203	1.098	1.034	1.153	0.940
	LectureHQ-Reisslein	0.856	0.849	0.836	0.841	0.837	0.855	0.920	0.880	0.909	0.904	0.921
	LectureHQ-Reisslein	1.128	1.091	1.033	1.067	0.983	0.960	0.987	0.894	0.824	0.803	0.764
	ParkingLot	0.413	0.370	0.390	0.431	0.469	0.499	0.540	0.673	0.748	0.719	0.742
	ParkingLot	0.954	0.732	0.586	0.394	0.499	0.332	0.410	0.410	0.416	0.525	0.469
CIF	*Silence of the Lambs*	0.928	0.896	0.890	0.925	0.956	0.914	0.921	0.825	0.857	0.898	0.832
040608.Q.	*Silence of the Lambs*	1.136	1.212	1.167	1.049	1.074	1.120	1.041	1.120	1.031	1.015	1.186
No.R.C.	*Terminator One*	0.824	0.820	0.807	0.808	0.802	0.854	0.910	0.909	0.920	0.964	0.959
	Terminator One	1.125	1.098	1.023	0.926	0.921	0.767	0.838	0.742	0.692	0.813	0.732
	Snowboard with Comm	0.743	0.719	0.672	0.614	0.598	0.616	0.583	0.636	0.555	0.533	0.560
	Snowboard with Comm	1.172	1.084	0.850	0.833	0.807	0.705	0.592	0.634	0.700	0.661	0.533
	Oprah w/o Comm	0.868	0.838	0.815	0.812	0.818	0.833	0.775	0.758	0.847	0.665	0.748
	Oprah w/o Comm	1.169	1.214	1.203	1.107	1.065	0.978	1.145	1.090	0.942	1.112	0.903
	LectureHQ-Reisslein	0.862	0.851	0.841	0.845	0.853	0.882	0.924	0.908	0.944	0.977	0.994
	LectureHQ-Reisslein	1.107	1.068	1.017	1.054	0.986	0.967	1.006	0.938	0.873	0.887	0.840
	ParkingLot	0.384	0.336	0.349	0.393	0.435	0.470	0.516	0.649	0.708	0.665	0.696
	ParkingLot	0.941	0.723	0.568	0.343	0.436	0.278	0.369	0.376	0.330	0.459	0.386
CIF	*Silence of the Lambs*	0.931	0.898	0.888	0.920	0.939	0.896	0.905	0.818	0.834	0.895	0.830
060810.Q.	*Silence of the Lambs*	1.098	1.177	1.169	1.044	1.052	1.101	1.024	1.137	1.013	1.029	1.197
No.R.C.	*Terminator One*	0.823	0.813	0.801	0.800	0.797	0.853	0.903	0.904	0.922	0.966	0.961
	Terminator One	1.105	1.091	1.015	0.916	0.907	0.761	0.848	0.731	0.677	0.811	0.717
	Snowboard with Comm	0.750	0.726	0.682	0.619	0.600	0.617	0.582	0.640	0.547	0.537	0.536
	Snowboard with Comm	1.153	1.083	0.875	0.863	0.816	0.700	0.625	0.641	0.729	0.675	0.557

Table 3: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	Oprah w/o Comm	0.859	0.827	0.795	0.780	0.783	0.794	0.730	0.731	0.809	0.633	0.674
	Oprah w/o Comm	1.139	1.192	1.184	1.085	1.062	0.967	1.113	1.118	0.905	1.075	0.878
	LectureHQ-Reisslein	0.867	0.856	0.852	0.855	0.861	0.890	0.929	0.915	0.952	1.005	1.028
	LectureHQ-Reisslein	1.096	1.063	1.012	1.044	0.981	0.984	1.012	0.947	0.889	0.916	0.863
	ParkingLot	0.371	0.321	0.329	0.375	0.424	0.449	0.500	0.626	0.686	0.631	0.666
	ParkingLot	0.936	0.714	0.546	0.334	0.402	0.252	0.342	0.371	0.278	0.397	0.336
CIF	*Silence of the Lambs*	0.935	0.902	0.893	0.921	0.930	0.892	0.901	0.816	0.813	0.894	0.837
H.M.Q.	*Silence of the Lambs*	1.083	1.166	1.148	1.033	1.045	1.104	1.010	1.111	1.013	1.029	1.194
No.R.C.	*Terminator One*	0.821	0.809	0.798	0.797	0.794	0.857	0.898	0.899	0.925	0.965	0.964
	Terminator One	1.099	1.092	1.012	0.909	0.890	0.760	0.835	0.725	0.671	0.818	0.713
	Snowboard with Comm	0.755	0.731	0.689	0.626	0.605	0.619	0.584	0.638	0.546	0.543	0.532
	Snowboard with Comm	1.138	1.087	0.887	0.881	0.839	0.704	0.656	0.664	0.767	0.699	0.611
	Oprah w/o Comm	0.848	0.813	0.783	0.760	0.757	0.766	0.701	0.695	0.770	0.619	0.649
	Oprah w/o Comm	1.133	1.184	1.185	1.073	1.053	0.960	1.086	1.081	0.877	1.057	0.854
	LectureHQ-Reisslein	0.867	0.859	0.857	0.857	0.854	0.887	0.907	0.891	0.923	0.980	1.013
	LectureHQ-Reisslein	1.096	1.062	1.016	1.034	0.972	0.981	0.992	0.921	0.887	0.897	0.830
	ParkingLot	0.367	0.317	0.326	0.370	0.427	0.453	0.503	0.631	0.694	0.649	0.674
	ParkingLot	0.939	0.710	0.537	0.334	0.389	0.249	0.345	0.388	0.257	0.388	0.332
CIF	*Silence of the Lambs*	0.937	0.914	0.908	0.924	0.906	0.871	0.880	0.791	0.791	0.884	0.823
M.Q.	*Silence of the Lambs*	1.046	1.130	1.127	1.016	1.023	1.075	0.989	1.072	1.002	1.027	1.180
No.R.C.	*Terminator One*	0.813	0.796	0.784	0.779	0.776	0.842	0.877	0.893	0.922	0.963	0.951
	Terminator One	1.062	1.078	0.995	0.890	0.873	0.755	0.762	0.713	0.642	0.807	0.683
	Snowboard with Comm	0.759	0.734	0.690	0.622	0.602	0.616	0.577	0.622	0.519	0.531	0.471
	Snowboard with Comm	1.105	1.070	0.903	0.883	0.836	0.580	0.646	0.607	0.668	0.617	0.576
	Oprah w/o Comm	0.858	0.818	0.779	0.757	0.749	0.729	0.690	0.685	0.731	0.614	0.638
	Oprah w/o Comm	1.065	1.134	1.148	1.053	1.062	0.950	1.069	1.036	0.859	1.068	0.845
	LectureHQ-Reisslein	0.867	0.858	0.852	0.850	0.847	0.865	0.887	0.893	0.906	0.977	1.006
	LectureHQ-Reisslein	1.081	1.048	1.019	1.057	0.997	1.010	1.034	0.960	0.920	0.950	0.913
	ParkingLot	0.356	0.303	0.310	0.358	0.429	0.437	0.494	0.616	0.676	0.606	0.673
	ParkingLot	0.942	0.705	0.528	0.311	0.370	0.222	0.321	0.358	0.265	0.343	0.282
CIF	*Silence of the Lambs*	0.919	0.907	0.900	0.911	0.880	0.828	0.861	0.744	0.758	0.876	0.819
M.L.Q.	*Silence of the Lambs*	0.999	1.101	1.095	1.015	1.023	1.036	0.914	0.950	0.952	1.085	1.071
No.R.C.	*Terminator One*	0.797	0.779	0.768	0.759	0.763	0.807	0.830	0.840	0.890	0.905	0.906
	Terminator One	1.013	1.039	0.990	0.896	0.877	0.720	0.701	0.739	0.603	0.732	0.693
	Snowboard with Comm	0.773	0.741	0.698	0.637	0.623	0.604	0.599	0.606	0.500	0.547	0.436
	Snowboard with Comm	1.060	1.040	0.927	0.932	0.873	0.684	0.684	0.603	0.723	0.671	0.584
	Oprah w/o Comm	0.851	0.839	0.815	0.789	0.789	0.721	0.696	0.678	0.688	0.546	0.626
	Oprah w/o Comm	0.969	1.053	1.096	1.032	1.087	0.985	1.052	1.042	0.885	1.017	0.930
	LectureHQ-Reisslein	0.833	0.815	0.800	0.784	0.755	0.716	0.737	0.745	0.725	0.735	0.778
	LectureHQ-Reisslein	1.030	1.012	0.967	0.989	0.942	0.885	0.920	0.926	0.863	0.855	0.774
	ParkingLot	0.340	0.285	0.290	0.331	0.440	0.466	0.513	0.637	0.701	0.628	0.729
	ParkingLot	0.930	0.688	0.491	0.237	0.318	0.178	0.325	0.395	0.279	0.367	0.414
CIF	*Silence of the Lambs*	0.911	0.898	0.902	0.892	0.864	0.814	0.857	0.738	0.749	0.852	0.816
L.Q.	*Silence of the Lambs*	0.984	1.073	1.065	0.997	1.018	1.023	0.900	0.903	0.950	1.090	1.027
No.R.C.	*Terminator One*	0.787	0.771	0.762	0.741	0.741	0.786	0.794	0.816	0.866	0.869	0.884
	Terminator One	1.001	1.021	0.970	0.905	0.889	0.743	0.687	0.770	0.616	0.733	0.681
	Snowboard with Comm	0.778	0.744	0.704	0.651	0.642	0.609	0.638	0.583	0.521	0.582	0.462
	Snowboard with Comm	1.043	1.028	0.920	0.916	0.889	0.671	0.642	0.604	0.710	0.665	0.585
	Oprah w/o Comm	0.816	0.808	0.783	0.760	0.742	0.725	0.702	0.651	0.663	0.571	0.646
	Oprah w/o Comm	0.933	1.004	1.060	0.989	1.056	0.977	0.966	0.976	0.862	0.913	0.948
	LectureHQ-Reisslein	0.832	0.817	0.798	0.784	0.762	0.749	0.741	0.773	0.797	0.757	0.784
	LectureHQ-Reisslein	0.998	0.995	0.981	1.005	0.965	0.902	0.986	0.954	0.885	0.861	0.788
	ParkingLot	0.335	0.277	0.276	0.312	0.416	0.487	0.502	0.625	0.684	0.619	0.746
	ParkingLot	0.936	0.693	0.497	0.188	0.290	0.123	0.338	0.337	0.283	0.451	0.432
CIF	*Silence of the Lambs*	0.791	0.780	0.781	0.759	0.726	0.776	0.733	0.721	0.827	0.797	0.756
64 kbps	*Silence of the Lambs*	0.886	0.951	0.977	0.961	0.934	1.051	0.798	0.821	0.851	0.824	1.033
R.C.	*Terminator One*	0.793	0.776	0.762	0.741	0.736	0.776	0.777	0.805	0.857	0.854	0.866
	Terminator One	0.998	1.016	0.969	0.908	0.912	0.776	0.714	0.753	0.631	0.738	0.692
	Snowboard with Comm	0.777	0.741	0.703	0.652	0.644	0.611	0.639	0.586	0.533	0.577	0.471
	Snowboard with Comm	1.035	1.020	0.918	0.922	0.864	0.667	0.637	0.612	0.703	0.671	0.584
	Oprah w/o Comm	0.825	0.791	0.786	0.742	0.697	0.658	0.647	0.610	0.594	0.553	0.533
	Oprah w/o Comm	0.898	0.939	1.000	0.922	0.956	0.866	0.808	0.852	0.683	0.699	0.631
	LectureHQ-Reisslein	0.487	0.490	0.526	0.517	0.495	0.438	0.428	0.402	0.415	0.434	0.466
	LectureHQ-Reisslein	0.647	0.592	0.667	0.564	0.476	0.168	0.158	-0.008	-0.013	0.062	0.039
	ParkingLot	0.330	0.273	0.270	0.302	0.403	0.480	0.486	0.600	0.655	0.615	0.737
	ParkingLot	0.934	0.677	0.484	0.157	0.301	0.132	0.360	0.323	0.268	0.416	0.437
CIF	*Silence of the Lambs*	0.475	0.488	0.495	0.482	0.456	0.495	0.395	0.419	0.497	0.484	0.464
128 kbps	*Silence of the Lambs*	0.809	0.985	1.041	0.919	0.854	0.576	0.158	0.345	-0.072	-0.019	-0.243
R.C.	*Terminator One*	0.456	0.465	0.453	0.440	0.396	0.371	0.336	0.527	0.378	0.420	0.329
	Terminator One	0.666	0.612	0.454	0.277	0.026	-0.089	-0.173	-0.162	-0.020	-0.186	-0.291
	Snowboard with Comm	0.581	0.573	0.576	0.552	0.538	0.451	0.450	0.523	0.439	0.456	0.413
	Snowboard with Comm	0.774	0.722	0.661	0.568	0.627	0.526	0.236	0.104	0.038	-0.022	-0.056
	Oprah w/o Comm	0.443	0.437	0.418	0.450	0.454	0.409	0.546	0.396	0.590	0.327	0.466
	Oprah w/o Comm	0.533	0.451	0.278	0.021	-0.090	-0.023	-0.105	-0.147	0.055	0.126	-0.466
	LectureHQ-Reisslein	0.364	0.398	0.430	0.433	0.395	0.534	0.553	0.405	0.546	0.531	0.570
	LectureHQ-Reisslein	0.101	0.015	-0.076	-0.025	0.162	0.130	0.206	-0.009	0.074	0.072	0.258
	ParkingLot	0.289	0.244	0.226	0.201	0.257	0.220	0.266	0.270	0.288	0.345	0.436
	ParkingLot	0.559	0.406	0.311	0.132	0.175	-0.044	-0.037	-0.196	0.029	-0.100	0.177
CIF	*Silence of the Lambs*	0.367	0.411	0.322	0.354	0.432	0.363	0.431	0.650	0.957	0.633	1.123
256 kbps	*Silence of the Lambs*	0.443	0.481	0.391	0.131	-0.142	0.010	-0.026	-0.271	0.120	-0.013	0.283
R.C.	*Terminator One*	0.287	0.300	0.321	0.288	0.310	0.395	0.541	0.349	0.531	0.657	0.797
	Terminator One	-0.039	-0.045	-0.073	-0.112	-0.022	0.188	0.029	-0.091	0.359	0.181	0.099
	Snowboard with Comm	0.382	0.386	0.323	0.408	0.429	0.344	0.414	0.365	0.446	0.509	0.548

Table 3: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	Snowboard with Comm	0.185	0.066	-0.104	0.030	-0.166	-0.102	-0.003	-0.131	0.008	-0.118	0.124
	Oprah w/o Comm	0.309	0.342	0.385	0.381	0.439	0.591	0.823	0.885	0.887	0.799	1.254
	Oprah w/o Comm	0.012	0.023	-0.029	-0.040	0.024	0.251	0.248	0.264	0.276	0.169	0.585
	LectureHQ-Reisslein	0.222	0.226	0.235	0.233	0.314	0.386	0.445	0.378	0.624	0.634	0.819
	LectureHQ-Reisslein	-0.025	-0.086	-0.108	-0.109	0.037	0.092	0.053	0.039	0.126	0.109	-0.009
	ParkingLot	0.379	0.380	0.384	0.373	0.276	0.437	0.353	0.307	0.415	0.426	0.291
	ParkingLot	0.413	0.262	-0.023	-0.132	-0.128	-0.203	-0.115	-0.070	-0.151	0.028	-0.015

Long range dependence is measured in terms of the Hurst parameter (H), which lies in the range of $0.5 \leq H \leq 1$. A Hurst parameter value of 0.5 means that the sequence does not have long range dependence; a value of $0.5 < H < 0.75$ indicates weak long range dependence and a value of $0.75 < H \leq 1$ indicates strong long range dependence. Generally speaking, a larger H means stronger long range dependence. Estimates of long range dependence are more accurate when taken at higher aggregation levels a, typically $a > 192$. Thus, any comparisons that are made with the Hurst parameter need to be made with estimates at aggregation levels $a > 192$. See [1] and [2] for more information about the Hurst parameter.

The long range dependence behavior is same as was found in the single layer encoded video sequences discussed in Part2 of the technical report series. From Table 3 we observe that, as the aggregation level increases for a given quality level, the H estimates tend to oscillate. We further observe that the H estimates of a video trace for different quality levels do not show a consistent behavior. Some show decreasing H estimates as the quality decreases (*Silence of the Lambs*), whereas others show a oscillatory behavior. However, we observe that as the quality level changes, there is a small change in H estimate and practically this change is negligible concluding that long range dependence cannot be changed by changing the quality level of encodings; it rather appears to be a property of the source video sequence. Of all the sequences, *ParkingLot* is the only sequence which does not exhibit long range dependence (H estimate is around 0.5). This can also be concluded from the nearly exponential decay of the autocorrelation plot of the frame sizes. *Snowboard with Comm* exhibits a weak long range dependence with $H = 0.6$ as frame size autocorrelation plots show a nearly exponential decay.

For rate control encodings, we conclude that there is no long range dependence for target bit rates of 128 kbps and 256 kbps as $H < 0.5$ in most of the cases. For a target bit rate of 64 kbps some video sequences exhibits a weak long range dependence (*Oprah w/o Comm*), some show a strong long range dependence (*Silence of the Lambs*), others show no long range dependence (*LectureHQ-Reisslein*).

Table 4 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. Figures 7, 8, and 9 give the variance-time plots, the pox plots of R/S (for $a = 12$), and the periodogram (for $a = 12$). It is observed that the H estimates from the variance time plots are very close to the H estimates given by the R/S plots at the aggregation level of $a = 192$ for encodings without rate control. Hurst parameter estimate from the periodogram technique tends to give a higher H value than the corresponding H obtained using the R/S estimate or the variance time analysis. This is because of the linear fit used to estimate H, which heavily depends on the region from where the samples are chosen. This is unlike the R/S or the variance time test where there are relatively very few samples available for the linear fit. For encodings with rate control, we find that H values estimated from the R/S plots, are quite different from that of variance time plots where both indicate that there is hardly any long range dependence.

Some logscale diagrams are given in Figure 10. We observe that the logscale diagrams give, in many cases, H estimates very close to one or above one, which should be viewed with caution. The H estimates around and above one appear to be due to the fact that the employed logscale estimation assumes Gaussian time series, whereas our trace data is typically non-Gaussian.

The logscale diagrams in Figure 10 typically exhibit a "knee" around scale $j = 4$ or $j = 5$. This time scale, which corresponds to roughly 16 to 32 frames (i.e., about half a second to one second of video) may be a transition point from short-term to long-term scaling. For the longer scales, the logscale plots indicate a reasonable level of scaling, with some "bumps" for very large scales. We find the same logscale behavior in the single layer encoding statistics given in table 4 of Part2 of the technical report series.

We observe that the normalized form $\underline{c}_f$ tends to be very large for video encodings with logscale $H < 0$. We further observe that as the quality of the encoding decreases, the $\underline{c}_f$ estimation either tends to decrease (*Silence of the Lambs*) or remains nearly unchanged (*LectureHQ-Reisslein*).

Table 4: Hurst parameters estimated from variance time plot, scaling parameters estimated from logscale diagram for base layer traffic.

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
CIF H.Q. No.R.C.	*Silence of the Lambs*	0.911	0.023	1.011	1.005
	Terminator One	0.791	0.036	1.005	1.003
	Snowboard with Comm	0.455	0.199	0.8	0.900
	Oprah w/o Comm	0.868	0.001	1.488	1.244
	LectureHQ-Reisslein	0.83	0.005	1.053	1.026
	ParkingLot	0.535	101181.964	-1.482	-0.241
CIF 040608.Q. No.R.C.	*Silence of the Lambs*	0.899	0	1.891	1.446
	Terminator One	0.780	0.014	0.987	0.994
	Snowboard with Comm	0.447	0.053	0.835	0.918
	Oprah w/o Comm	0.828	0.003	1.032	1.016
	LectureHQ-Reisslein	0.832	0.003	0.889	0.944
	ParkingLot	0.473	39175.261	-1.525	-0.262
CIF 060810.Q. No.R.C.	*Silence of the Lambs*	0.892	0	1.840	1.420
	Terminator One	0.772	0.016	0.976	0.988
	Snowboard with Comm	0.445	0.054	0.852	0.926
	Oprah w/o Comm	0.788	0.004	1.027	1.013
	LectureHQ-Reisslein	0.833	0.003	0.884	0.942
	ParkingLot	0.438	53227.020	-1.582	-0.291
CIF H.M.Q. No.R.C.	*Silence of the Lambs*	0.889	0	1.772	1.386
	Terminator One	0.771	0.03	0.971	0.986
	Snowboard with Comm	0.437	0.096	0.856	0.928
	Oprah w/o Comm	0.754	0.012	1.011	1.005
	LectureHQ-Reisslein	0.822	0.005	0.899	0.949
	ParkingLot	0.443	70820.273	-1.562	-0.281

Table 4: *continued*

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
CIF	*Silence of the Lambs*	0.881	0	1.698	1.349
M.Q.	*Terminator One*	0.756	0.015	0.944	0.972
No.R.C.	*Snowboard with Comm*	0.423	0.036	0.868	0.934
	Oprah w/o Comm	0.716	0.002	1.034	1.017
	LectureHQ-Reisslein	0.837	0.001	0.969	0.985
	ParkingLot	0.408	49346.157	-1.659	-0.329
CIf	*Silence of the Lambs*	0.86	0.002	1.4	1.200
M.L.Q.	*Terminator One*	0.724	0.032	0.896	0.948
No.R.C.	*Snowboard with Comm*	0.425	0.048	0.873	0.936
	Oprah w/o Comm	0.669	0.004	1.102	1.051
	LectureHQ-Reisslein	0.719	0.003	0.922	0.961
	ParkingLot	0.382	5173.761	-1.413	-0.206
CIF	*Silence of the Lambs*	0.845	0.003	1.34	1.170
L.Q.	*Terminator One*	0.704	0.036	0.877	0.938
No.R.C.	*Snowboard with Comm*	0.45	0.045	0.867	0.933
	Oprah w/o Comm	0.602	0.004	1.105	1.053
	LectureHQ-Reisslein	0.664	0.003	0.886	0.943
	ParkingLot	0.35	30439.724	-1.698	-0.349
CIF	*Silence of the Lambs*	0.791	0.007	0.98	0.990
64 kbps	*Terminator One*	0.703	0.036	0.879	0.939
R.C.	*Snowboard with Comm*	0.46	0.045	0.862	0.931
	Oprah w/o Comm	0.522	0.008	1	1.000
	LectureHQ-Reisslein	0.363	1058.407	-1.465	-0.233
	ParkingLot	0.334	47506.306	-1.763	-0.382
CIF	*Silence of the Lambs*	-0.911	1.00675E+18	-5.965	-2.482
128 kbps	*Terminator One*	0.019	95575.049	-2.135	-0.567
R.C.	*Snowboard with Comm*	-1.007	0.182	0.328	0.664
	Oprah w/o Comm	-0.387	2855.483	-1.997	-0.499
	LectureHQ-Reisslein	0.267	0.053	-0.877	0.061
	ParkingLot	-0.246	33093.125	-1.685	-0.343
CIF	*Silence of the Lambs*	0.244	549.708	-1.93	-0.465
256 kbps	*Terminator One*	0.023	0.066	-0.846	0.077
R.C.	*Snowboard with Comm*	0.246	18.341	-1.476	-0.238
	Oprah w/o Comm	0.238	0.029	-0.771	0.114
	LectureHQ-Reisslein	0.161	0.5	-1.112	-0.056
	ParkingLot	-0.12	17.744	-1.585	-0.292

Table 5 gives the scaling parameters α_q for the orders $q = 0.5$, 1, 1.5, 2, 2.5, 3, 3.5, and 4. Figures 11 and 12 give the multiscale diagrams and the linear multiscale diagrams. It can be observed that the scaling parameters increase with increasing q with the exception of the scaling parameters which are negative (in such a case, the scaling parameter decreases as q increases, see *ParkingLot*). With the decrease in the quality of encoding of a given video sequence, the scaling parameter tends to be oscillatory. The Hurst parameter estimate is given by $H = \alpha_2/2$. We observe from Table 5 that in some cases the H estimate is larger than 1, this is because multiscale estimation assumes a Gaussian time series, whereas the traces are typically non-Gaussian. In summary from the R/S, periodogram, variance test, logscale and multiscale Hurst parameter estimates we can conclude that for video encodings without rate control the *ParkingLot* sequence does not exhibit any long range dependence and *Silence of the Lambs* exhibits the strongest long range dependence. For rate control encodings with 128 kbps and 256 kbps, none exhibits long range dependence, whereas some videos at 64 kbps do exhibit weak long range dependence. This is because rate control at 64 kbps is not effective in some cases and can be visualized as a low quality encoding.

Table 5: Scaling parameters estimated from multiscale diagram for base layer traffic.

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
CIF	*Silence of the Lambs*	0.506	0.992	1.482	1.979	2.468	2.939	3.391	3.829
H.Q.	*Terminator One*	0.514	1.009	1.488	1.949	2.394	2.823	3.235	3.632
No.R.C.	*Snowboard with Comm*	0.475	0.924	1.356	1.776	2.186	2.589	2.987	3.376
	Oprah w/o Comm	0.629	1.255	1.875	2.504	3.133	3.752	4.359	4.955
	LectureHQ-Reisslein	0.499	1.017	1.551	2.093	2.646	3.216	3.771	4.323
	ParkingLot	-0.257	-0.491	-0.703	-0.895	-1.070	-1.234	-1.394	-1.555
CIF	*Silence of the Lambs*	0.949	1.704	2.377	3.006	3.610	4.198	4.778	5.352
040608.Q.	*Terminator One*	0.501	0.990	1.469	1.925	2.361	2.781	3.184	3.571
No.R.C.	*Snowboard with Comm*	0.480	0.938	1.379	1.810	2.234	2.654	3.069	3.481
	Oprah w/o Comm	0.530	1.054	1.558	2.030	2.462	2.853	3.211	3.546
	LectureHQ-Reisslein	0.480	0.931	1.371	1.813	2.258	2.701	3.135	3.559
	ParkingLot	-0.263	-0.531	-0.782	-1.012	-1.227	-1.434	-1.639	-1.847
CIF	*Silence of the Lambs*	0.910	1.660	2.345	2.989	3.606	4.205	4.794	5.376
060810.Q.	*Terminator One*	0.495	0.980	1.458	1.910	2.345	2.762	3.165	3.551
No.R.C.	*Snowboard with Comm*	0.484	0.943	1.388	1.825	2.257	2.685	3.111	3.534
	Oprah w/o Comm	0.534	1.053	1.552	2.019	2.446	2.832	3.185	3.515
	LectureHQ-Reisslein	0.482	0.934	1.373	1.814	2.259	2.699	3.128	3.544
	ParkingLot	-0.287	-0.581	-0.859	-1.114	-1.354	-1.586	-1.817	-2.051
CIF	*Silence of the Lambs*	0.874	1.610	2.290	2.931	3.546	4.144	4.730	5.309
H.M.Q.	*Terminator One*	0.491	0.974	1.446	1.902	2.334	2.751	3.154	3.542
No.R.C.	*Snowboard with Comm*	0.485	0.945	1.392	1.831	2.265	2.696	3.124	3.550
	Oprah w/o Comm	0.530	1.046	1.541	2.005	2.429	2.813	3.164	3.490
	LectureHQ-Reisslein	0.486	0.942	1.387	1.834	2.284	2.729	3.160	3.577
	ParkingLot	-0.296	-0.581	-0.845	-1.089	-1.317	-1.537	-1.756	-1.978
CIF	*Silence of the Lambs*	0.795	1.543	2.264	2.952	3.612	4.253	4.879	5.494
M.Q.	*Terminator One*	0.490	0.960	1.415	1.865	2.286	2.691	3.081	3.457
No.R.C.	*Snowboard with Comm*	0.482	0.945	1.395	1.840	2.280	2.719	3.155	3.588
	Oprah w/o Comm	0.549	1.078	1.580	2.039	2.447	2.810	3.140	3.450
	LectureHQ-Reisslein	0.471	0.953	1.442	1.933	2.422	2.908	3.390	3.854
	ParkingLot	-0.338	-0.664	-0.966	-1.241	-1.497	-1.740	-1.979	-2.219
CIF	*Silence of the Lambs*	0.558	1.154	1.773	2.406	3.045	3.675	4.288	4.884
M.L.Q.	*Terminator One*	0.474	0.924	1.361	1.797	2.203	2.597	2.980	3.351

Table 5: *continued*

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
No.R.C.	*Snowboard with Comm*	0.475	0.938	1.393	1.844	2.292	2.736	3.175	3.607
	Oprah w/o Comm	0.551	1.109	1.666	2.206	2.718	3.201	3.661	4.103
	LectureHQ-Reisslein	0.504	0.975	1.439	1.910	2.389	2.844	3.282	3.696
	ParkingLot	-0.175	-0.317	-0.439	-0.552	-0.664	-0.780	-0.901	-1.029
CIF	*Silence of the Lambs*	0.551	1.136	1.737	2.345	2.956	3.565	4.159	4.736
L.Q.	*Terminator One*	0.470	0.915	1.347	1.777	2.178	2.567	2.946	3.312
No.R.C.	*Snowboard with Comm*	0.466	0.924	1.379	1.829	2.275	2.716	3.150	3.576
	Oprah w/o Comm	0.523	1.050	1.586	2.123	2.653	3.175	3.688	4.187
	LectureHQ-Reisslein	0.488	0.955	1.409	1.862	2.297	2.700	3.091	3.457
	ParkingLot	-0.238	-0.465	-0.666	-0.844	-1.009	-1.168	-1.324	-1.483
CIF	*Silence of the Lambs*	0.464	1.038	1.601	2.121	2.590	3.038	3.469	3.922
64 kbps	*Terminator One*	0.470	0.916	1.347	1.774	2.173	2.559	2.935	3.300
R.C.	*Snowboard with Comm*	0.463	0.919	1.375	1.829	2.280	2.729	3.172	3.610
	Oprah w/o Comm	0.511	1.027	1.529	2.011	2.468	2.901	3.314	3.710
	LectureHQ-Reisslein	0.105	0.038	-0.273	-0.677	-1.106	-1.541	-1.977	-2.412
	ParkingLot	-0.243	-0.486	-0.711	-0.915	-1.104	-1.283	-1.457	-1.633
CIF	*Silence of the Lambs*	-0.216	-1.705	-3.567	-5.393	-7.183	-8.951	-10.702	-12.443
128 kbps	*Terminator One*	-0.003	-0.281	-0.727	-1.232	-1.751	-2.273	-2.796	-3.322
R.C.	*Snowboard with Comm*	0.304	0.639	0.976	1.305	1.626	1.942	2.250	2.554
	Oprah w/o Comm	0.023	-0.111	-0.463	-0.921	-1.410	-1.908	-2.411	-2.917
	LectureHQ-Reisslein	0.000	0.030	0.073	0.112	0.135	0.135	0.113	0.071
	ParkingLot	-0.204	-0.398	-0.585	-0.773	-0.966	-1.165	-1.372	-1.584
CIF	*Silence of the Lambs*	0.085	0.008	-0.344	-0.919	-1.573	-2.235	-2.889	-3.534
256 kbps	*Terminator One*	0.059	0.102	0.136	0.164	0.183	0.194	0.198	0.194
R.C.	*Snowboard with Comm*	-0.087	-0.177	-0.267	-0.357	-0.451	-0.550	-0.645	-0.758
	Oprah w/o Comm	0.053	0.087	0.140	0.213	0.300	0.392	0.481	0.563
	LectureHQ-Reisslein	-0.028	-0.048	-0.066	-0.089	-0.124	-0.180	-0.259	-0.361
	ParkingLot	-0.206	-0.369	-0.517	-0.679	-0.875	-1.119	-1.409	-1.735

2.2 Enhancement Layer Traffic

Table 6 gives the mean frame size $\bar{X}^e$, the coefficient of variation CoV_X^e, and the peak-to-mean ratio $X_{\max}^e/\bar{X}^e$ of the enhancement layer frame sizes along with the mean bit rate $\bar{X}^e/T$ and the peak bit rate $X_{\max}^e/T$.

Focusing for now on the encodings without rate control, as the quantization parameter increases (quality of encoding decreases) we find that the enhancement layer mean frame size decreases, except for the H.M.Q quality encoding where all video encodings (with the exception of *Snowboard with Commercials*) give a larger mean frame size than the 060810.Q encodings. Further investigation of this effect is needed. We further observe that the average enhancement layer frame sizes are 2 to 3 times larger than the corresponding average base layer frame sizes for videos encoded without rate control. Since the enhancement layer increases the format of the decoded frame by a factor of four, we would expect that the enhancement layer is an average of roughly three times larger than the base layer. However there is no consistent behavior in this ratio as the quality of the encoding changes for a given video.

We also observe that for most of the encodings, the enhancement layer traffic is smoother (CoV_X^e is small for smooth traffic) than the base layer traffic with exception of a few. This effect is especially significant for the medium and low quality encodings. It is also observed that the CoV_X^e varies over a narrower range as compared to the variation of the CoV_X^b for different encodings. The peak to mean ratio ($\bar{X}^e/\bar{X}^b$) is 1 to 1.5 times larger than the corresponding $X_{\max}^b/\bar{X}^b$. The CoV_X^e and $\bar{X}^e/\bar{X}^b$ generally increase a little bit as the quality of the encoding decreases indicating the fact that low quality encoded video traffic tends to be more bursty. The combined effect of the reduced variability and increased average of the enhancement layer traffic on providers of scalable video services over networks will be studied in detail in future work.

We next turn to the enhancement layer frame size statistics for the encodings with rate control. Recall from Part 1 that the rate control is applied only to the base layer. The enhancement layer is encoded with the fixed quantization parameters 10 for I frames, 14 for P frames, and 16 for B frames, which we refer to as the medium quality level. Indeed, the frame size statistics of the enhancement layer of the rate controlled encodings are roughly equal to the corresponding statistics of the medium quality encodings without rate control. It is also interesting to note that these enhancement layers, which are encoded without rate control are significantly smoother than the base layers, which are encoded with rate control (albeit with a scheme that strives to provide rate control at the GoP time scale).

We remind here again that the enhancement layer is not rate controlled, rate control is applied only for base layer. This is the reason why we do not see a constant frame size in enhancement layer for rate controlled encodings. For a given encoding mode, *Silence of the Lambs* has the smallest mean frame size in the enhancement layer and *ParkingLot* has the largest mean frame size. For encodings ranging from the high quality to the H.M quality, we observe that the mean frame size of *Oprah w/o Commercials* is larger than for *Terminator I*, but from the medium quality onwards this reverses. When compared to the corresponding base layer mean frame size, *Silence of the lambs* has the smallest mean frame size, *ParkingLot* has the largest frame size in encodings without rate control and 64 kbps target bit rate control encoding.

We observe that the mean frame size in the enhancement layer varies slightly. This indicates that the amount of traffic generated in the enhancement layer is effected by the base layer encoding type and quality. This is because the larger the target bit rate at the base layer, the more information the video captures in the base layer, leaving less information for the enhancement layer.

Table 6: Overview of frame statistics of the enhancement layer of spatial scalable encoded video

		Frame Size			Bit Rate	
Enc. M.	Video	Mean $\bar{X}^e$ [kbyte]	CoV CoV_X^e	Peak/Mean $X^e_{\max}/\bar{X}^e$	Mean $\bar{X}^e/T$ [Mbps]	Peak $X^e_{\max}/T$ [Mbps]
CIF H.Q. No.R.C.	*Silence of the Lambs*	5.765	0.757	8.654	1.384	11.974
	Terminator One	8.560	0.607	6.189	2.054	12.716
	Snowboard with Comm	13.831	0.391	4.351	3.319	14.442
	Oprah w/o Comm	16.564	0.255	2.635	3.975	10.475
	LectureHQ-Reisslein	6.307	0.395	6.704	1.514	10.147
	ParkingLot	17.793	0.378	3.928	4.270	16.773
CIF 040608.Q. No.R.C.	*Silence of the Lambs*	1.843	1.262	19.209	0.442	8.498
	Terminator One	3.465	0.885	10.461	0.831	8.698
	Snowboard with Comm	5.048	0.644	7.185	1.211	8.705
	Oprah w/o Comm	5.256	0.410	4.998	1.261	6.304
	LectureHQ-Reisslein	2.050	0.912	13.929	0.492	6.852
	ParkingLot	7.362	0.658	6.907	1.767	12.204
CIF 060810.Q. No.R.C.	*Silence of the Lambs*	1.337	1.343	20.609	0.321	6.611
	Terminator One	2.625	0.943	12.017	0.630	7.570
	Snowboard with Comm	3.581	0.701	8.278	0.859	7.114
	Oprah w/o Comm	3.426	0.438	6.581	0.822	5.412
	LectureHQ-Reisslein	1.154	1.125	21.162	0.277	5.861
	ParkingLot	4.324	0.860	9.466	1.038	9.824
CIF H.M.Q. No.R.C.	*Silence of the Lambs*	1.386	1.247	16.844	0.333	5.601
	Terminator One	2.661	0.895	11.862	0.639	7.576
	Snowboard with Comm	3.544	0.658	8.423	0.851	7.165
	Oprah w/o Comm	3.440	0.402	6.553	0.826	5.410
	LectureHQ-Reisslein	1.472	0.728	16.661	0.353	5.885
	ParkingLot	5.280	0.639	6.492	1.267	8.227
CIF M.Q. No.R.C.	*Silence of the Lambs*	0.720	1.423	25.621	0.173	4.429
	Terminator One	1.494	1.053	16.105	0.359	5.775
	Snowboard with Comm	1.797	0.797	11.815	0.431	5.094
	Oprah w/o Comm	1.478	0.518	12.089	0.355	4.288
	LectureHQ-Reisslein	0.693	0.940	25.367	0.166	4.218
	ParkingLot	2.698	0.793	9.354	0.647	6.056
CIF M.L.Q. No.R.C.	*Silence of the Lambs*	0.514	1.218	28.571	0.123	3.528
	Terminator One	1.016	1.039	18.614	0.244	4.539
	Snowboard with Comm	1.102	0.788	14.739	0.264	3.897
	Oprah w/o Comm	0.859	0.540	16.873	0.206	3.479

Table 6: *continued*

	LectureHQ-Reisslein	0.464	0.780	29.009	0.111	3.233
	ParkingLot	1.559	0.772	9.770	0.374	3.655
CIF L.Q. No.R.C.	*Silence of the Lambs*	0.436	1.103	30.074	0.105	3.147
	Terminator One	0.826	1.034	19.712	0.198	3.910
	Snowboard with Comm	0.859	0.773	16.443	0.206	3.389
	Oprah w/o Comm	0.641	0.564	19.342	0.154	2.976
	LectureHQ-Reisslein	0.373	0.728	31.906	0.090	2.859
	ParkingLot	1.152	0.768	11.456	0.276	3.167
CIF 64 kbps R.C.	*Silence of the Lambs*	0.836	1.369	22.070	0.201	4.428
	Terminator One	1.757	0.946	13.711	0.422	5.782
	Snowboard with Comm	2.047	0.822	10.700	0.491	5.257
	Oprah w/o Comm	1.827	0.584	9.848	0.439	4.320
	LectureHQ-Reisslein	0.776	1.184	22.801	0.186	4.245
	ParkingLot	2.981	0.864	8.661	0.716	6.197
CIF 128 kbps R.C.	*Silence of the Lambs*	0.732	1.506	25.145	0.176	4.420
	Terminator One	1.622	1.016	14.873	0.389	5.789
	Snowboard with Comm	1.988	0.831	11.018	0.477	5.257
	Oprah w/o Comm	1.635	0.553	10.883	0.392	4.270
	LectureHQ-Reisslein	0.704	0.992	25.010	0.169	4.226
	ParkingLot	2.965	0.859	8.678	0.712	6.175
CIF 256 kbps R.C.	*Silence of the Lambs*	0.676	1.556	27.201	0.162	4.415
	Terminator One	1.432	1.128	16.760	0.344	5.760
	Snowboard with Comm	1.828	0.835	11.862	0.439	5.203
	Oprah w/o Comm	1.433	0.569	12.511	0.344	4.302
	LectureHQ-Reisslein	0.689	0.894	25.422	0.165	4.204
	ParkingLot	2.797	0.815	9.142	0.671	6.137

Table 7 gives the mean GoP sizes ($\bar{Y}^e$), the coefficients of variation of the GoP sizes (CoV_Y^e), and the peak-to-mean ratio ($Y^e_{\max}/\bar{Y}^e$) of the GoP sizes, as well as the peak bit rate ($Y^b_{\max}/(GT)$).

We observe that the CoV_Y^e and $Y^e_{\max}/\bar{Y}^e$ of video sequences encoded without rate control have slightly higher values (around 10 to 30 percent) when compared with the corresponding values for base layer traffic given in Table 2, in some encodings they are nearly equal. As the quality of the encoding decreases, the CoV_Y^e and $Y^e_{\max}/\bar{Y}^e$ values generally increases indicating that low quality video is bursty in nature. For rate controlled encodings, we find that the CoV_Y^e and $Y^e_{\max}/\bar{Y}^e$ are almost equal for target bit rates of 64, 128, and 256 kbps and are little bit higher when compared with the corresponding CoV_Y^b and $Y^b_{\max}/\bar{Y}^b$. This is because the enhancement layer traffic is not rate controlled (rate control is applied only for base layer) and the fact that MPEG trys to maintain a constant quality at variable traffic. The GoP statistics for encodings with the target bit rates 64, 128, and 256 kbps have similar values with very slight changes because we encoded the enhancement layer with Medium Quality (I=10, P=14, B=16). Slight changes in values are because the type of encoding in base layer effects enhancement layer traffic.

As per general expectation the mean GoP size ($\bar{Y}^e$) in the enhancement layer is quite large (roughly 3 times) when compared to the base layer mean GoP frame size ($\bar{Y}^b$) because the enhancement layer is encoded in the CIF format (where the CIF frame format is 4 times larger than the QCIF frame format).

Table 7: Overview of GoP statistics of the enhancement layer of spatial scalable encoded video

		GoP Size			Peak
		Mean	CoV	Peak/Mean	Bit Rate
Enc. M.	Video	$\bar{Y}^e$ [kbyte]	CoV_Y^e	$Y^e_{\max}/\bar{Y}^e$	$Y^e_{\max}/(GT)$ [Mbps]
CIF H.Q. No.R.C.	*Silence of the Lambs*	69.182	0.658	6.182	8.554
	Terminator One	102.724	0.427	2.844	5.843
	Snowboard with Comm	165.970	0.361	2.889	9.590
	Oprah w/o Comm	198.773	0.245	1.886	7.497
	LectureHQ-Reisslein	75.681	0.235	2.894	4.381
	ParkingLot	213.511	0.328	2.965	12.663
CIF 040608.Q. No.R.C.	*Silence of the Lambs*	22.119	1.004	10.269	4.543
	Terminator One	41.575	0.533	3.398	2.826
	Snowboard with Comm	60.572	0.529	4.310	5.221
	Oprah w/o Comm	63.072	0.334	2.571	3.243
	LectureHQ-Reisslein	24.597	0.315	3.886	1.912
	ParkingLot	88.344	0.493	4.094	7.234
CIF 060810.Q. No.R.C.	*Silence of the Lambs*	16.040	1.054	11.189	3.589
	Terminator One	31.499	0.555	3.432	2.162
	Snowboard with Comm	42.971	0.581	4.872	4.187
	Oprah w/o Comm	41.116	0.364	2.844	2.339
	LectureHQ-Reisslein	13.847	0.548	5.126	1.420
	ParkingLot	51.892	0.712	5.664	5.878
CIF H.M.Q. No.R.C.	*Silence of the Lambs*	16.626	1.001	10.585	3.520
	Terminator One	31.936	0.542	3.330	2.127
	Snowboard with Comm	42.532	0.576	4.842	4.119
	Oprah w/o Comm	41.279	0.353	2.788	2.302

Table 7: *continued*

	LectureHQ-Reisslein	17.662	0.319	4.005	1.415
	ParkingLot	63.358	0.542	4.543	5.757
CIF	*Silence of the Lambs*	8.643	1.085	12.425	2.148
M.Q.	*Terminator One*	17.930	0.598	3.647	1.308
No.R.C.	*Snowboard with Comm*	21.560	0.667	5.977	2.577
	Oprah w/o Comm	17.735	0.418	3.865	1.371
	LectureHQ-Reisslein	8.315	0.358	4.411	0.734
	ParkingLot	32.373	0.649	5.720	3.704
CIF	*Silence of the Lambs*	6.173	0.916	10.941	1.351
M.L.Q.	*Terminator One*	12.192	0.586	3.951	0.963
No.R.C.	*Snowboard with Comm*	13.220	0.653	6.182	1.635
	Oprah w/o Comm	10.308	0.386	4.227	0.871
	LectureHQ-Reisslein	5.572	0.300	4.061	0.453
	ParkingLot	18.706	0.649	6.386	2.389
CIF	*Silence of the Lambs*	5.231	0.819	9.969	1.043
L.Q.	*Terminator One*	9.918	0.577	4.264	0.846
No.R.C.	*Snowboard with Comm*	10.306	0.633	6.187	1.275
	Oprah w/o Comm	7.693	0.378	4.408	0.678
	LectureHQ-Reisslein	4.480	0.273	3.958	0.355
	ParkingLot	13.823	0.644	6.762	1.869
CIF	*Silence of the Lambs*	10.030	1.068	12.221	2.452
64 kbps	*Terminator One*	21.084	0.570	3.648	1.538
R.C.	*Snowboard with Comm*	24.567	0.620	5.451	2.678
	Oprah w/o Comm	21.930	0.369	3.271	1.435
	LectureHQ-Reisslein	9.309	0.374	4.350	0.810
	ParkingLot	35.776	0.613	5.383	3.852
CIF	*Silence of the Lambs*	8.788	1.201	13.949	2.452
128 kbps	*Terminator One*	19.461	0.637	3.952	1.538
R.C.	*Snowboard with Comm*	23.858	0.653	5.613	2.678
	Oprah w/o Comm	19.617	0.435	3.647	1.431
	LectureHQ-Reisslein	8.448	0.379	4.753	0.803
	ParkingLot	35.579	0.619	5.413	3.851
CIF	*Silence of the Lambs*	8.116	1.197	15.102	2.451
256 kbps	*Terminator One*	17.183	0.658	4.249	1.460
R.C.	*Snowboard with Comm*	21.931	0.694	6.058	2.657
	Oprah w/o Comm	17.191	0.464	3.992	1.373
	LectureHQ-Reisslein	8.268	0.355	4.717	0.780
	ParkingLot	33.565	0.667	5.680	3.813

Figure 13 gives the frame size X_n^e (in byte) as a function of the frame number n. From the plots we observe that *Oprah w/o Commercials* has the least variability, whereas *Snowboard with Commercials* and *Silence of the Lambs* both have higher variability (black regions in the plot indicate high density of samples and the wider the black region is, the wider the samples are distributed). Comparing Figure 13 and Figure 1 (*Oprah w/o Commercials*), we clearly notice the increase in the peak-to-mean ratio in the enhancement layer traffic as the mean of the plots remains almost constant, however the peaks are higher in the enhancement layer traffic. Similar behavior is observed for *Snowboard with Commercials.* Plots b and e of Figure 13 look similar, as the 128 kbps target bit rate has enhancement layer set to the medium quality level. The other two plots (d and f) should look similar to the corresponding medium quality encodings.

Figure 14 gives the GoP size Y_m^e (in bytes) as a function of the GoP number m. For encodings without rate control these plots look similar to corresponding GoP plots for the base layer traffic. This is corroborated by the fact that the coefficients of variation for the base layer and the enhancement layer (GoP level) have nearly the same values and peak-to-mean ratios are close as reported in Table 2 and 7. As the enhancement layer is encoded in Medium quality, we observe that the plots d,e, and f (which are encoded at the target bit rates 64, 128, and 256 kbps) are similar to the GoP level enhancement layer traffic plot for videos encoded without rate control at Medium quality.

The observations and conclusions made from Figure 13 and Figure 14 are further strengthened by Figure 15 which gives the histograms of the frame sizes X_n^e. The wider the histogram, the higher is variance of the traffic. Similar to earlier observations, the encodings with rate control have almost the same histograms as one would obtain from the corresponding enhancement layer of Medium quality encoded videos.

Figure 16 gives the autocorrelation coefficient $\rho_X^e(k)$ of the frame size sequence X_n^e, $n = 0, \ldots, N-1$, as a function of the lag k (in frames). We observe that the autocorrelation function, is a series of spikes superimposed on a decreasing slope curve. High magnitude spikes are due to relatively large sizes of P frames in a GoP as compared to B frames. The frequency of these large magnitude spikes is a 12 frame lag, corresponding to the P frame frequency in the enhancement layer. However, in this plots we do not observe intermediate spikes as was observed in single layer autocorrelation function plots. In addition, we find that the relative difference between the maximum and minimum value of the spikes is smaller than what is found in the corresponding single layer autocorrelation function. This is because of the GoP structure difference (single layer has I frames which are far larger than P and B frames, thus we find a large spike followed by a few smaller spikes due to P-P and B-B correlation). We further notice that unlike the previous autocorrelation plots observed for base layer and single layer traffic, the autocorrelation plots in the enhancement layer tend to be smooth in between spikes (for Medium and Low quality). This is because there are only P and B frames in the enhancement layer and inside a GoP, many a times B frames can be of almost same sizes. This leads to near exponential decay in between spikes (because autocorrelation of step function and another step function is a exponential decay).

We further notice that for rate controlled sequences, the autocorrelation plot is similar to the ones for Medium quality encodings without rate control. Figure 17 gives the autocorrelation coefficient $\rho_{Y^e}(k)$ of the GoP size sequence $Y_m^e,\ m = 0, \ldots, N/G-1$, as a function of the lag k (in GoPs). We find near exponential decay for *Snowboard with Comm* and *Oprah w/o Comm*, the former taking 40 GoP duration and the latter taking 80 GoP duration to drop to zero. This might indicate a weak long range dependence. We also observe that for videos encoded without rate control, the GoP size autocorrelation for enhancement layer is similar to the one obtained for base layer traffic except for a level shift in the enhancement layer and we found the same difference for encodings with rate control.

Table 8 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 and Figure 19, and Figure 20 gives the corresponding plots. It is found that the Hurst parameter estimates from the R/S plot and the periodogram for the enhancement layer traffic are almost the same as the one obtained for base layer traffic considering encodings of similar quality (without rate control) with the exception of only one video, namely the *ParkingLot* at 060810 quality encoding. This again indicates that the long range dependence property of a video sequence does not change with scaling. For CIF spatial encodings, we choose the base layer to be in the QCIF format (which is a scaled down version of CIF sequence) whereas the enhancement layer in the CIF format. This is because scaling changes the encoded frame size, but it does not effect the successive frame size relation (relative) which means that autocorrelation function slope is relatively unchanged, thus not effecting the long range dependence estimation (compare Figure 17 for enhancement layer GoP level autocorrelation function and Figure 6 for base layer GoP level autocorrelation function).

The observations made for Hurst parameter estimation given in Table 3 for encodings without rate control are also valid for Table 8, as the H estimation in the enhancement layer is nearly equal to that of the base layer traffic.

For encodings with rate control, as the enhancement layer is encoded with Medium quality (rate control is applied for only base layer) we observe that the H estimate differs from that of Table 3. These new value of H estimation is equal to that obtained for Medium quality encodings of enhancement layer and all three encoding types 64, 128, 256 kbps show little variation in the H estimates (this little change is because rate control is applied to the base layer) but they do not effect the final decision about the long range dependence from the H parameter.

Table 8: Hurst parameters estimated from pox diagram of R/S and periodogram as a function of the aggregation level a for enhancement layer traffic.

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
CIF	*Silence of the Lambs*	0.921	0.906	0.911	0.929	0.971	0.935	0.942	0.828	0.859	0.897	0.814
H.Q.	*Silence of the Lambs*	1.168	1.245	1.176	1.049	1.066	1.117	1.020	1.138	1.034	1.063	1.148
No.R.C.	*Terminator One*	0.833	0.826	0.826	0.826	0.838	0.881	0.908	0.919	0.937	0.973	0.959
	Terminator One	1.115	1.098	1.023	0.930	0.933	0.855	0.841	0.802	0.721	0.923	0.785
	Snowboard with Comm	0.719	0.686	0.638	0.583	0.537	0.569	0.478	0.554	0.513	0.427	0.453
	Snowboard with Comm	1.193	1.086	0.820	0.804	0.746	0.704	0.531	0.581	0.632	0.504	0.475
	Oprah w/o Comm	0.858	0.840	0.834	0.832	0.834	0.895	0.807	0.831	0.929	0.736	0.823
	Oprah w/o Comm	1.280	1.249	1.227	1.121	1.115	1.064	1.163	1.107	1.057	1.079	0.964
	LectureHQ-Reisslein	0.877	0.875	0.852	0.848	0.812	0.798	0.818	0.809	0.772	0.740	0.746
	LectureHQ-Reisslein	1.103	1.097	1.086	1.102	1.014	1.032	1.088	0.960	0.889	0.987	0.827
	ParkingLot	0.494	0.455	0.475	0.484	0.472	0.500	0.548	0.652	0.760	0.674	0.785
	ParkingLot	0.959	0.764	0.628	0.482	0.535	0.375	0.272	0.294	0.404	0.468	0.443
CIF	*Silence of the Lambs*	0.920	0.904	0.913	0.919	0.936	0.894	0.907	0.804	0.827	0.913	0.820
040608.Q.	*Silence of the Lambs*	1.056	1.157	1.137	1.036	1.013	1.099	1.059	1.153	1.021	1.164	1.245
No.R.C.	*Terminator One*	0.819	0.802	0.798	0.793	0.814	0.872	0.892	0.906	0.948	0.995	1.001
	Terminator One	1.070	1.059	0.997	0.901	0.892	0.796	0.810	0.750	0.664	0.841	0.715
	Snowboard with Comm	0.738	0.701	0.660	0.619	0.582	0.600	0.532	0.583	0.478	0.475	0.436
	Snowboard with Comm	1.163	1.075	0.859	0.871	0.814	0.756	0.654	0.698	0.770	0.626	0.668
	Oprah w/o Comm	0.847	0.817	0.797	0.776	0.780	0.839	0.735	0.743	0.852	0.657	0.777
	Oprah w/o Comm	1.191	1.209	1.218	1.086	1.076	1.004	1.071	1.046	0.921	1.124	0.882
	LectureHQ-Reisslein	0.859	0.852	0.837	0.833	0.827	0.843	0.860	0.836	0.849	0.875	0.901
	LectureHQ-Reisslein	1.070	1.043	1.007	1.023	0.943	0.957	0.958	0.895	0.839	0.830	0.768
	ParkingLot	0.441	0.399	0.420	0.457	0.478	0.497	0.571	0.640	0.731	0.662	0.753
	ParkingLot	0.926	0.729	0.565	0.371	0.465	0.275	0.246	0.268	0.249	0.393	0.373
	Silence of the Lambs	0.919	0.906	0.908	0.911	0.924	0.884	0.898	0.792	0.811	0.909	0.816
CIF	*Silence of the Lambs*	1.031	1.124	1.110	1.023	1.001	1.080	1.036	1.129	1.021	1.159	1.180
060810.Q.	*Terminator One*	0.811	0.793	0.788	0.779	0.797	0.861	0.876	0.898	0.937	0.970	0.996
No.R.C.	*Terminator One*	1.054	1.044	0.992	0.892	0.886	0.781	0.807	0.730	0.648	0.804	0.686
	Snowboard with Comm	0.739	0.703	0.666	0.627	0.599	0.602	0.552	0.586	0.462	0.492	0.443
	Snowboard with Comm	1.152	1.069	0.873	0.892	0.827	0.726	0.679	0.755	0.791	0.639	0.664
	Oprah w/o Comm	0.839	0.808	0.787	0.759	0.763	0.812	0.708	0.713	0.820	0.651	0.729
	Oprah w/o Comm	1.158	1.185	1.209	1.074	1.066	0.981	1.032	1.049	0.881	1.097	0.865
	LectureHQ-Reisslein	0.901	0.899	0.895	0.890	0.870	0.921	0.880	0.874	0.947	0.923	0.920
	LectureHQ-Reisslein	1.091	1.092	1.073	1.130	1.143	1.113	1.166	1.216	1.124	1.281	1.186
	ParkingLot	0.566	0.556	0.620	0.715	0.747	0.858	0.860	0.888	0.995	0.870	0.956
	ParkingLot	1.077	0.965	0.906	0.788	0.954	0.917	1.042	1.117	1.154	1.204	1.233
CIF	*Silence of the Lambs*	0.919	0.907	0.910	0.912	0.927	0.889	0.899	0.795	0.820	0.909	0.815
H.M.Q.	*Silence of the Lambs*	1.038	1.135	1.117	1.026	1.001	1.080	1.034	1.116	1.017	1.149	1.191
No.R.C.	*Terminator One*	0.811	0.793	0.788	0.777	0.797	0.860	0.876	0.897	0.936	0.970	0.998
	Terminator One	1.056	1.042	0.997	0.895	0.888	0.777	0.804	0.728	0.645	0.810	0.684
	Snowboard with Comm	0.734	0.698	0.660	0.621	0.592	0.602	0.547	0.585	0.466	0.485	0.440
	Snowboard with Comm	1.138	1.061	0.861	0.880	0.817	0.714	0.661	0.714	0.762	0.622	0.660
	Oprah w/o Comm	0.840	0.809	0.788	0.762	0.766	0.809	0.704	0.710	0.817	0.654	0.723
	Oprah w/o Comm	1.154	1.191	1.205	1.071	1.051	0.968	1.019	1.038	0.874	1.099	0.857
	LectureHQ-Reisslein	0.851	0.840	0.825	0.825	0.823	0.842	0.846	0.844	0.855	0.908	0.924
	LectureHQ-Reisslein	1.052	1.026	0.995	1.004	0.937	0.946	0.952	0.908	0.830	0.832	0.796
	ParkingLot	0.423	0.380	0.397	0.442	0.477	0.493	0.571	0.623	0.714	0.632	0.747
	ParkingLot	0.915	0.716	0.538	0.337	0.442	0.238	0.238	0.278	0.225	0.364	0.359
CIF	*Silence of the Lambs*	0.912	0.904	0.905	0.898	0.896	0.853	0.872	0.761	0.780	0.888	0.807
M.Q.	*Silence of the Lambs*	0.992	1.079	1.068	1.023	0.988	1.064	1.035	1.041	1.019	1.120	1.119
No.R.C.	*Terminator One*	0.792	0.778	0.770	0.761	0.768	0.832	0.836	0.869	0.903	0.918	0.958
	Terminator One	1.022	1.007	0.969	0.865	0.886	0.736	0.763	0.706	0.592	0.727	0.631
	Snowboard with Comm	0.748	0.710	0.679	0.651	0.623	0.593	0.594	0.581	0.460	0.528	0.434
	Snowboard with Comm	1.123	1.059	0.894	0.925	0.839	0.695	0.727	0.688	0.792	0.656	0.604
	Oprah w/o Comm	0.844	0.815	0.783	0.749	0.747	0.768	0.703	0.680	0.792	0.645	0.689
	Oprah w/o Comm	1.067	1.125	1.180	1.074	1.063	0.952	1.022	1.052	0.867	0.977	0.876
	LectureHQ-Reisslein	0.839	0.834	0.820	0.815	0.805	0.844	0.841	0.849	0.875	0.944	0.952
	LectureHQ-Reisslein	1.029	0.989	0.953	0.950	0.875	0.896	0.900	0.897	0.785	0.828	0.724
	ParkingLot	0.395	0.348	0.358	0.414	0.487	0.510	0.579	0.607	0.674	0.616	0.734
	ParkingLot	0.904	0.690	0.503	0.272	0.402	0.220	0.251	0.283	0.225	0.349	0.343
CIF	*Silence of the Lambs*	0.906	0.901	0.899	0.893	0.889	0.833	0.859	0.746	0.769	0.875	0.797
M.L.Q.	*Silence of the Lambs*	0.986	1.074	1.060	1.006	0.984	1.027	0.985	0.965	0.985	1.058	1.087
No.R.C.	*Terminator One*	0.780	0.768	0.761	0.750	0.752	0.816	0.809	0.838	0.880	0.885	0.927
	Terminator One	0.996	0.983	0.951	0.853	0.866	0.725	0.724	0.743	0.589	0.727	0.636
	Snowboard with Comm	0.744	0.706	0.676	0.651	0.630	0.583	0.600	0.568	0.474	0.539	0.416
	Snowboard with Comm	1.098	1.028	0.888	0.922	0.838	0.661	0.718	0.598	0.724	0.636	0.519
	Oprah w/o Comm	0.828	0.819	0.781	0.740	0.738	0.741	0.685	0.668	0.746	0.672	0.704
	Oprah w/o Comm	0.996	1.067	1.129	1.066	1.052	0.925	1.006	1.036	0.863	0.970	0.871
	LectureHQ-Reisslein	0.827	0.814	0.795	0.792	0.780	0.795	0.799	0.819	0.840	0.866	0.892
	LectureHQ-Reisslein	0.996	0.968	0.938	0.930	0.874	0.833	0.915	0.877	0.714	0.799	0.688
	ParkingLot	0.375	0.328	0.335	0.391	0.491	0.526	0.574	0.597	0.654	0.612	0.730

Table 8: *continued*

		Aggregation level a [frames]										
Enc. M.	Video	12	24	48	96	192	300	396	504	600	696	792
	ParkingLot	0.903	0.664	0.468	0.248	0.374	0.209	0.259	0.249	0.210	0.320	0.319
CIF	*Silence of the Lambs*	0.903	0.896	0.893	0.884	0.866	0.822	0.851	0.743	0.762	0.857	0.792
L.Q.	*Silence of the Lambs*	0.978	1.065	1.043	0.998	0.981	0.989	0.957	0.930	0.975	1.040	1.047
No.R.C.	*Terminator One*	0.776	0.765	0.759	0.746	0.754	0.806	0.801	0.825	0.869	0.869	0.921
	Terminator One	0.985	0.971	0.949	0.859	0.866	0.729	0.706	0.801	0.597	0.731	0.653
	Snowboard with Comm	0.749	0.709	0.680	0.654	0.635	0.583	0.610	0.559	0.484	0.571	0.424
	Snowboard with Comm	1.087	1.017	0.887	0.917	0.838	0.646	0.702	0.577	0.685	0.641	0.479
	Oprah w/o Comm	0.817	0.810	0.774	0.741	0.740	0.733	0.681	0.640	0.717	0.618	0.664
	Oprah w/o Comm	0.954	1.026	1.074	1.042	1.077	0.958	0.984	1.036	0.869	0.931	0.888
	LectureHQ-Reisslein	0.815	0.803	0.786	0.776	0.742	0.741	0.749	0.789	0.779	0.749	0.798
	LectureHQ-Reisslein	0.982	0.949	0.935	0.931	0.884	0.846	0.918	0.889	0.769	0.807	0.707
	ParkingLot	0.366	0.318	0.323	0.374	0.496	0.531	0.566	0.595	0.646	0.617	0.734
	ParkingLot	0.911	0.658	0.468	0.222	0.362	0.187	0.273	0.252	0.231	0.358	0.388
CIF	*Silence of the Lambs*	0.922	0.914	0.918	0.909	0.906	0.883	0.901	0.791	0.811	0.927	0.844
64 kbps	*Silence of the Lambs*	1.019	1.092	1.082	1.032	1.023	1.043	1.015	1.078	1.038	1.140	1.161
R.C.	*Terminator One*	0.794	0.778	0.770	0.757	0.767	0.828	0.831	0.863	0.900	0.915	0.954
	Terminator One	1.030	1.012	0.968	0.876	0.897	0.708	0.782	0.701	0.596	0.717	0.624
	Snowboard with Comm	0.741	0.697	0.668	0.628	0.609	0.591	0.579	0.582	0.472	0.487	0.400
	Snowboard with Comm	1.103	1.031	0.861	0.899	0.821	0.667	0.691	0.628	0.730	0.600	0.572
	Oprah w/o Comm	0.847	0.819	0.790	0.761	0.758	0.774	0.704	0.686	0.791	0.652	0.690
	Oprah w/o Comm	1.058	1.138	1.175	1.064	1.049	0.942	1.014	1.036	0.866	1.005	0.871
	LectureHQ-Reisslein	0.848	0.840	0.824	0.819	0.819	0.857	0.839	0.859	0.884	0.965	0.974
	LectureHQ-Reisslein	1.072	1.022	0.957	0.979	0.911	0.904	0.923	0.912	0.930	0.878	0.850
	ParkingLot	0.395	0.348	0.358	0.412	0.481	0.496	0.564	0.607	0.674	0.606	0.733
	ParkingLot	0.903	0.682	0.498	0.291	0.395	0.212	0.238	0.273	0.190	0.320	0.347
CIF	*Silence of the Lambs*	0.917	0.902	0.906	0.894	0.877	0.851	0.862	0.758	0.769	0.873	0.807
128 kbps	*Silence of the Lambs*	0.999	1.077	1.071	1.015	1.032	1.090	1.052	1.031	1.052	1.133	1.160
R.C.	*Terminator One*	0.800	0.781	0.773	0.761	0.767	0.830	0.839	0.874	0.903	0.934	0.950
	Terminator One	1.048	1.026	0.975	0.885	0.878	0.739	0.780	0.710	0.599	0.732	0.641
	Snowboard with Comm	0.750	0.707	0.677	0.637	0.616	0.597	0.594	0.604	0.488	0.506	0.417
	Snowboard with Comm	1.129	1.060	0.887	0.923	0.834	0.693	0.737	0.665	0.775	0.639	0.606
	Oprah w/o Comm	0.844	0.812	0.789	0.752	0.751	0.762	0.698	0.672	0.779	0.649	0.685
	Oprah w/o Comm	1.097	1.144	1.168	1.083	1.067	0.963	1.016	1.049	0.861	0.975	0.871
	LectureHQ-Reisslein	0.843	0.838	0.822	0.815	0.807	0.846	0.835	0.853	0.874	0.935	0.963
	LectureHQ-Reisslein	1.046	1.014	0.962	0.970	0.887	0.896	0.900	0.889	0.797	0.841	0.738
	ParkingLot	0.404	0.357	0.370	0.425	0.494	0.509	0.576	0.616	0.694	0.619	0.752
	ParkingLot	0.918	0.691	0.522	0.318	0.413	0.232	0.275	0.290	0.215	0.326	0.374
CIF	*Silence of the Lambs*	0.912	0.902	0.900	0.891	0.874	0.844	0.857	0.755	0.761	0.869	0.814
256 kbps	*Silence of the Lambs*	0.993	1.066	1.076	1.024	1.015	1.110	1.028	0.998	1.066	1.066	1.155
R.C.	*Terminator One*	0.800	0.783	0.774	0.763	0.764	0.838	0.851	0.884	0.903	0.935	0.958
	Terminator One	1.025	1.009	0.979	0.879	0.882	0.761	0.777	0.728	0.600	0.742	0.655
	Snowboard with Comm	0.751	0.709	0.674	0.639	0.619	0.586	0.579	0.578	0.449	0.500	0.418
	Snowboard with Comm	1.143	1.063	0.899	0.924	0.839	0.698	0.729	0.702	0.830	0.658	0.619
	Oprah w/o Comm	0.839	0.801	0.775	0.741	0.740	0.746	0.687	0.658	0.753	0.630	0.666
	Oprah w/o Comm	1.086	1.130	1.169	1.074	1.064	0.947	1.003	1.049	0.841	0.972	0.868
	LectureHQ-Reisslein	0.849	0.844	0.829	0.824	0.819	0.863	0.851	0.868	0.881	0.944	0.981
	LectureHQ-Reisslein	1.034	1.001	0.953	0.966	0.899	0.892	0.935	0.914	0.798	0.850	0.757
	ParkingLot	0.400	0.352	0.362	0.417	0.482	0.496	0.573	0.597	0.666	0.593	0.733
	ParkingLot	0.921	0.705	0.516	0.280	0.403	0.228	0.240	0.273	0.217	0.314	0.328

Table 9 gives the Hurst parameter estimated using the variance time plot as well as the scaling parameters c_f and α (also expressed as $H = (1 + \alpha)/2$) estimated from the logscale diagram. With the exception of *ParkingLot* encoding at 060810 quality all H estimates obtained from the variance time plots tend to be nearly equal to the ones obtained for corresponding base layer traffic. The rate controlled sequences have similar H estimate from variance time plots (Figures 18) as they all are encoded with Medium quality and hence we find these values to be equal to Medium quality values (of enhancement layer). There is considerable difference in the H estimate obtained from logscale diagrams. Most of the estimates are greater than one, because of non-Gaussian traffic. It is quite interesting to note that *ParkingLot* exhibits long range dependence for large a.

Comparing the enhancement layer traffic logscale plots (Figure 21) with that of the base layer traffic (Figure 10) we find that *Silence of the Lambs* and *Oprah w/o Comm* show similar behavior whereas *Snowboard with Comm* shows a different behavior (for encodings without rate control). For encodings with rate control we find the logscale plots to be similar to the corresponding medium quality enhancement layer logscale plots.

As the quality of encoding decreases, we find normalized form $\underline{c}_f$ to decrease.

Table 9: Hurst parameters estimated from variance time plot, scaling parameters estimated from logscale diagram for enhancement layer traffic.

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
CIF	*Silence of the Lambs*	0.915	0.000	2.163	1.582
H.Q.	*Terminator One*	0.821	0.035	1.001	1
No.R.C.	*Snowboard with Comm*	0.437	0.221	0.827	0.914
	Oprah w/o Comm	0.868	0.001	1.598	1.299
	LectureHQ-Reisslein	0.816	0.006	1.135	1.067
	ParkingLot	0.563	0.048	0.982	0.991
CIF	*Silence of the Lambs*	0.899	0.000	2.156	1.578
040608.Q.	*Terminator One*	0.796	0.035	0.957	0.979
No.R.C.	*Snowboard with Comm*	0.442	0.159	0.839	0.919
	Oprah w/o Comm	0.808	0.034	0.980	0.990
	LectureHQ-Reisslein	0.779	0.015	0.848	0.924
	ParkingLot	0.510	845797.709	-1.765	-0.383
CIF	*Silence of the Lambs*	0.892	0.000	2.148	1.574
060810.Q.	*Terminator One*	0.785	0.038	0.937	0.968
No.R.C.	*Snowboard with Comm*	0.447	0.157	0.844	0.922
	Oprah w/o Comm	0.768	0.004	1.392	1.196
	LectureHQ-Reisslein	0.864	0.024	0.725	0.863
	ParkingLot	0.922	0.026	0.626	0.813
CIF	*Silence of the Lambs*	0.892	0.000	2.187	1.594
H.M.Q.	*Terminator One*	0.783	0.040	0.937	0.968
No.R.C.	*Snowboard with Comm*	0.437	0.177	0.842	0.921
	Oprah w/o Comm	0.763	0.005	1.402	1.201
	LectureHQ-Reisslein	0.778	0.012	0.985	0.992
	ParkingLot	0.483	772879.017	-1.758	-0.379
CIF	*Silence of the Lambs*	0.875	0.000	2.088	1.544
M.Q.	*Terminator One*	0.76	0.023	1.016	1.008
No.R.C.	*Snowboard with Comm*	0.468	0.154	0.849	0.925
	Oprah w/o Comm	0.713	0.020	1.113	1.056
	LectureHQ-Reisslein	0.726	0.013	0.953	0.976

Table 9: *continued*

		VT	Logscale Diagram		
Enc. M.	Video	H	$\underline{c}_f$	α	H
	ParkingLot	0.438	76946.563	-1.535	-0.267
CIF M.L.Q. No.R.C.	*Silence of the Lambs*	0.864	0.000	2.066	1.533
	Terminator One	0.745	0.029	0.974	0.987
	Snowboard with Comm	0.454	0.158	0.842	0.921
	Oprah w/o Comm	0.667	0.020	1.068	1.034
	LectureHQ-Reisslein	0.712	0.279	0.397	0.699
	ParkingLot	0.403	946.981	-0.967	0.016
CIF L.Q. No.R.C.	*Silence of the Lambs*	0.856	0.013	1.137	1.068
	Terminator One	0.739	0.027	0.99	0.995
	Snowboard with Comm	0.46	0.162	0.833	0.917
	Oprah w/o Comm	0.636	0.021	1.047	1.024
	LectureHQ-Reisslein	0.665	0.212	0.434	0.717
	ParkingLot	0.372	3360.478	-1.167	-0.084
CIF 64 kbps R.C.	*Silence of the Lambs*	0.879	0.000	2.011	1.505
	Terminator One	0.756	0.053	0.893	0.947
	Snowboard with Comm	0.42	0.126	0.848	0.924
	Oprah w/o Comm	0.723	0.012	1.117	1.059
	LectureHQ-Reisslein	0.808	1.315	0.126	0.563
	ParkingLot	0.435	160305.006	-1.659	-0.329
CIF 128 kbps R.C.	*Silence of the Lambs*	0.876	0.000	2.104	1.552
	Terminator One	0.759	0.055	0.9	0.95
	Snowboard with Comm	0.445	0.121	0.868	0.934
	Oprah w/o Comm	0.711	0.016	1.138	1.069
	LectureHQ-Reisslein	0.747	0.011	0.987	0.994
	ParkingLot	0.455	84688.982	-1.56	-0.28
CIF 256 kbps R.C.	*Silence of the Lambs*	0.867	0.000	2.156	1.578
	Terminator One	0.763	0.052	0.883	0.942
	Snowboard with Comm	0.455	0.153	0.848	0.924
	Oprah w/o Comm	0.696	0.023	1.101	1.051
	LectureHQ-Reisslein	0.743	0.012	0.979	0.99
	ParkingLot	0.44	132347.288	-1.593	-0.296

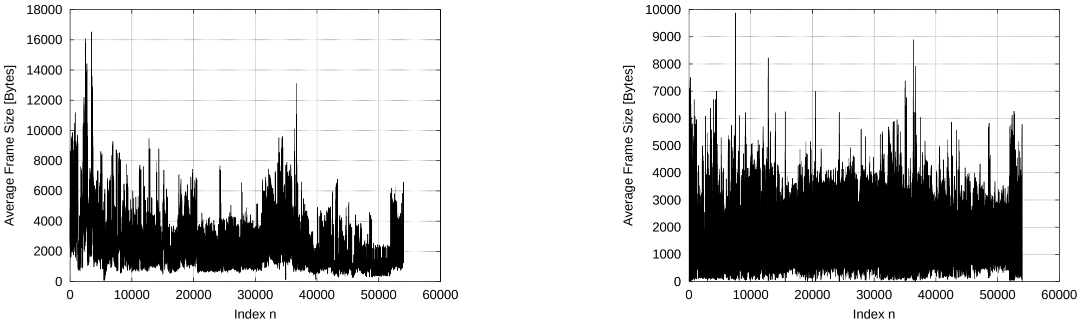
Table 10 gives the scaling parameters α_q for the orders $q = 0.5$, 1, 1.5, 2, 2.5, 3, 3.5, and 4. As was observed before, the scaling parameters increase with increasing q. The Hurst parameter estimates obtained from the multiscale diagram (Figures 22) for the enhancement layer are in many cases quite different, but we find some encodings which still behave alike in enhancement layer but there is no consistent trend in the behavior. *ParkingLot* encoded with High quality gives $H = 0.9$ indicating long range dependence, whereas for all other quality levels it does not show long range behavior. Multiscale parameters are alike for 64, 128, and 256 kbps target bit rate encodings. Figure 23 gives linear multiscale diagrams.

Table 10: Scaling parameters estimated from multiscale diagram for enhancement layer traffic.

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
CIF	*Silence of the Lambs*	0.992	1.847	2.625	3.359	4.065	4.752	5.424	6.086
H.Q.	*Terminator One*	0.513	1.003	1.480	1.947	2.406	2.860	3.306	3.744
No.R.C.	*Snowboard with Comm*	0.494	0.960	1.409	1.845	2.275	2.699	3.121	3.540
	Oprah w/o Comm	0.680	1.336	1.965	2.579	3.184	3.783	4.386	4.963
	LectureHQ-Reisslein	0.534	1.075	1.627	2.185	2.740	3.289	3.833	4.371
	ParkingLot	0.626	1.258	1.889	2.503	3.104	3.666	4.201	4.670
CIF	*Silence of the Lambs*	0.965	1.851	2.673	3.448	4.192	4.914	5.621	6.317
040608.Q.	*Terminator One*	0.475	0.949	1.422	1.893	2.355	2.813	3.266	3.716
No.R.C.	*Snowboard with Comm*	0.489	0.958	1.414	1.863	2.311	2.760	3.210	3.660
	Oprah w/o Comm	0.533	1.042	1.542	2.033	2.508	2.962	3.396	3.811
	LectureHQ-Reisslein	0.474	0.927	1.368	1.803	2.234	2.654	3.058	3.430
	ParkingLot	-0.353	-0.667	-0.938	-1.184	-1.419	-1.654	-1.892	-2.133
CIF	*Silence of the Lambs*	0.945	1.838	2.681	3.481	4.248	4.994	5.726	6.448
060810.Q.	*Terminator One*	0.468	0.935	1.404	1.871	2.330	2.784	3.233	3.678
No.R.C.	*Snowboard with Comm*	0.483	0.954	1.412	1.865	2.318	2.774	3.231	3.688
	Oprah w/o Comm	0.632	1.241	1.828	2.408	2.989	3.574	4.160	4.744
	LectureHQ-Reisslein	0.554	1.031	1.424	1.720	1.934	2.091	2.216	2.325
	ParkingLot	0.323	0.799	1.317	1.835	2.342	2.834	3.304	3.751
CIF	*Silence of the Lambs*	0.947	1.853	2.713	3.530	4.314	5.077	5.825	6.563
H.M.Q.	*Terminator One*	0.468	0.937	1.406	1.873	2.330	2.783	3.230	3.673
No.R.C.	*Snowboard with Comm*	0.482	0.951	1.408	1.860	2.313	2.768	3.225	3.684
	Oprah w/o Comm	0.641	1.251	1.836	2.412	2.991	3.574	4.157	4.741
	LectureHQ-Reisslein	0.497	1.003	1.507	2.000	2.483	2.962	3.443	3.917
	ParkingLot	-0.394	-0.709	-0.970	-1.210	-1.448	-1.690	-1.937	-2.191
CIF	*Silence of the Lambs*	0.909	1.815	2.683	3.514	4.318	5.104	5.877	6.642
M.Q.	*Terminator One*	0.507	0.998	1.484	1.956	2.433	2.906	3.375	3.841
No.R.C.	*Snowboard with Comm*	0.480	0.949	1.409	1.867	2.327	2.791	3.257	3.724
	Oprah w/o Comm	0.563	1.107	1.649	2.183	2.699	3.200	3.691	4.174
	LectureHQ-Reisslein	0.492	0.989	1.475	1.942	2.397	2.848	3.300	3.745
	ParkingLot	-0.317	-0.574	-0.799	-1.021	-1.252	-1.497	-1.755	-2.024
CIF	*Silence of the Lambs*	0.903	1.812	2.698	3.556	4.393	5.215	6.027	6.831
M.L.Q.	*Terminator One*	0.496	0.974	1.442	1.897	2.352	2.801	3.232	3.666
No.R.C.	*Snowboard with Comm*	0.477	0.945	1.402	1.858	2.317	2.779	3.241	3.699
	Oprah w/o Comm	0.554	1.103	1.646	2.170	2.671	3.152	3.618	4.073
	LectureHQ-Reisslein	0.428	0.808	1.101	1.280	1.350	1.342	1.291	1.221
	ParkingLot	-0.019	-0.046	-0.091	-0.157	-0.245	-0.350	-0.472	-0.606
CIF	*Silence of the Lambs*	0.532	1.067	1.591	2.089	2.556	2.989	3.394	3.779
L.Q.	*Terminator One*	0.510	0.998	1.468	1.920	2.360	2.788	3.207	3.618
No.R.C.	*Snowboard with Comm*	0.476	0.942	1.399	1.853	2.309	2.765	3.219	3.667
	Oprah w/o Comm	0.531	1.078	1.622	2.142	2.633	3.101	3.550	3.986
	LectureHQ-Reisslein	0.432	0.827	1.132	1.320	1.398	1.398	1.355	1.294
	ParkingLot	-0.053	-0.136	-0.222	-0.315	-0.419	-0.534	-0.661	-0.799
CIF	*Silence of the Lambs*	0.893	1.762	2.582	3.363	4.119	4.860	5.594	6.322
64 kbps	*Terminator One*	0.463	0.919	1.374	1.826	2.269	2.703	3.129	3.548

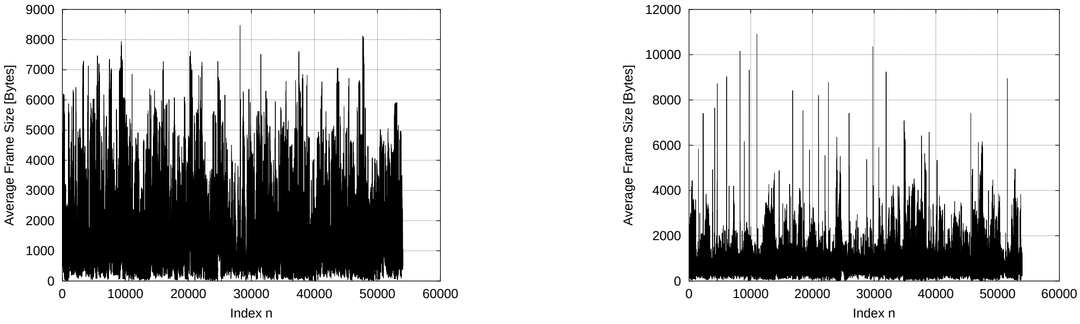
Table 10: *continued*

		Multiscale Diagram, α_q for							
Enc. M.	Video	$q = 0.5$	$q = 1$	$q = 1.5$	$q = 2$	$q = 2.5$	$q = 3$	$q = 3.5$	$q = 4$
R.C.	*Snowboard with Comm*	0.482	0.946	1.402	1.857	2.315	2.779	3.245	3.714
	Oprah w/o Comm	0.563	1.104	1.637	2.173	2.699	3.214	3.719	4.219
	LectureHQ-Reisslein	0.354	0.617	0.793	0.894	0.940	0.951	0.943	0.925
	ParkingLot	-0.373	-0.666	-0.922	-1.164	-1.406	-1.654	-1.908	-2.170
CIF	*Silence of the Lambs*	0.904	1.825	2.708	3.548	4.354	5.136	5.900	6.652
128 kbps	*Terminator One*	0.463	0.921	1.379	1.833	2.278	2.717	3.148	3.572
R.C.	*Snowboard with Comm*	0.487	0.957	1.418	1.876	2.338	2.803	3.272	3.742
	Oprah w/o Comm	0.562	1.110	1.653	2.196	2.725	3.242	3.748	4.247
	LectureHQ-Reisslein	0.503	1.005	1.493	1.967	2.431	2.893	3.352	3.802
	ParkingLot	-0.315	-0.597	-0.850	-1.088	-1.325	-1.565	-1.812	-2.064
CIF	*Silence of the Lambs*	0.923	1.857	2.765	3.636	4.478	5.299	6.103	6.897
256 kbps	*Terminator One*	0.461	0.919	1.374	1.820	2.258	2.687	3.107	3.521
R.C.	*Snowboard with Comm*	0.482	0.950	1.408	1.864	2.322	2.786	3.252	3.719
	Oprah w/o Comm	0.565	1.107	1.637	2.162	2.671	3.164	3.646	4.122
	LectureHQ-Reisslein	0.503	1.003	1.488	1.955	2.412	2.865	3.318	3.762
	ParkingLot	-0.322	-0.601	-0.852	-1.090	-1.326	-1.567	-1.815	-2.070



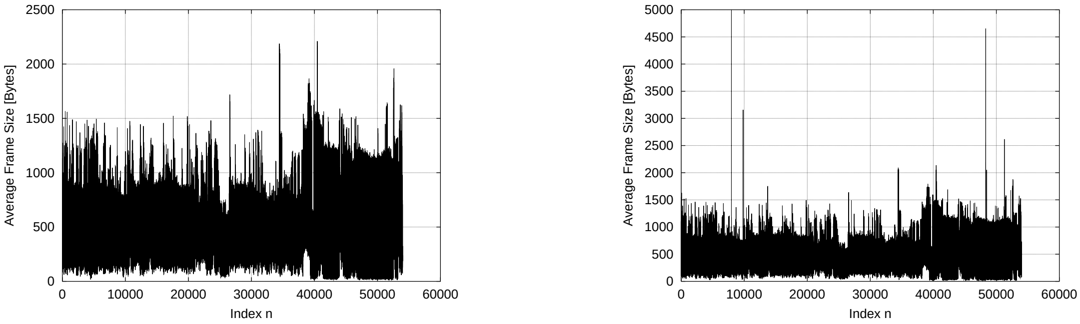
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



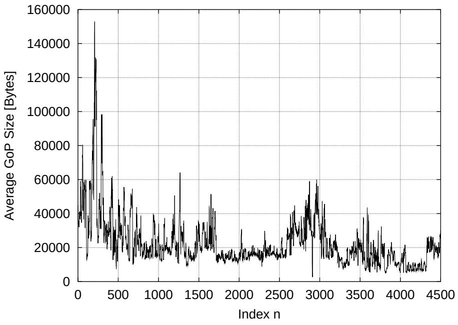
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

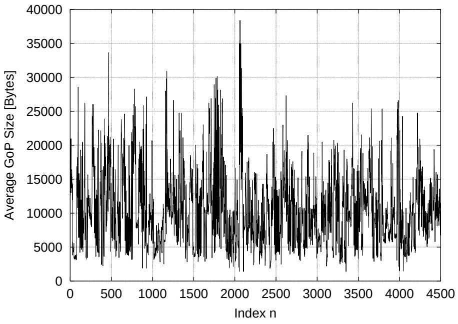
Encoding without rate control

Encoding with rate control

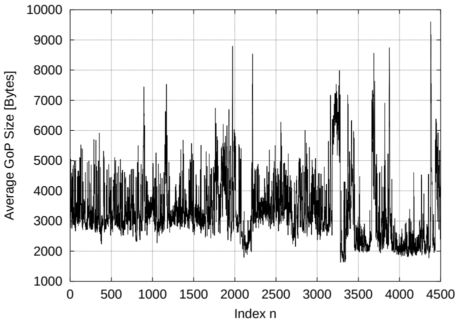
Figure 1: Base layer frame size X_n^b as a function of the frame index n for spatial scalable CIF video.



a) *Silence of the Lambs* with high quality

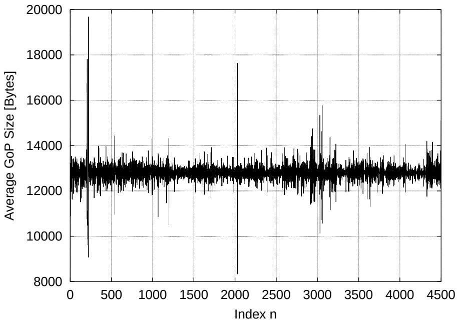


b) *Snowboard with Comm* with medium quality

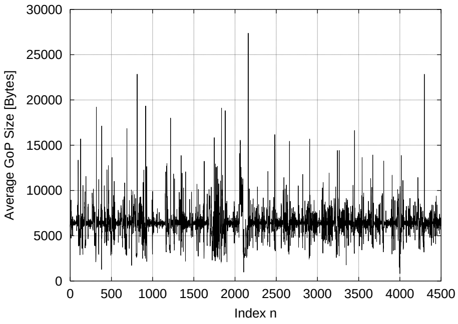


c) *Oprah w/o Comm* with low quality

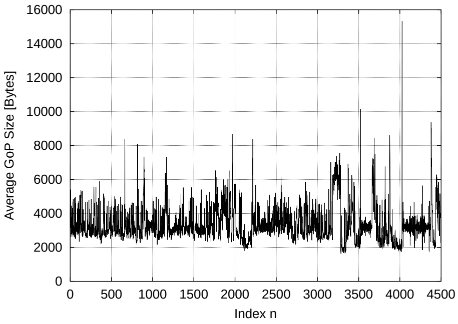
Encoding without rate control



d) *Silence of the Lambs* with 256 kbps target bit rate



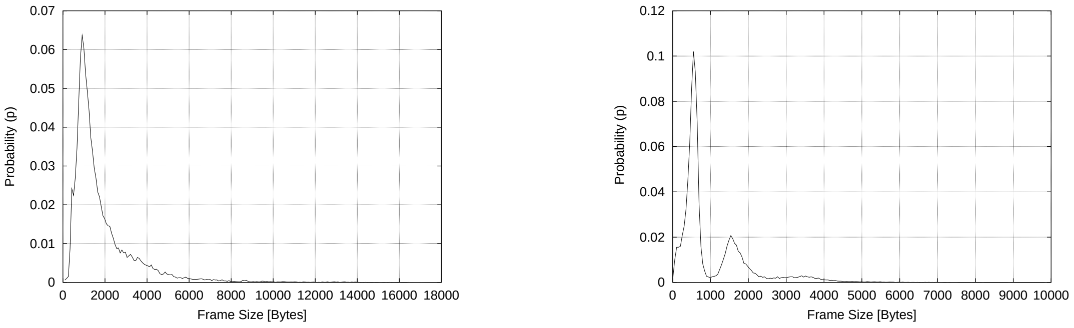
e) *Snowboard with Comm* with 128 kbps target bit rate



f) *Oprah w/o Comm* with 64 kbps target bit rate

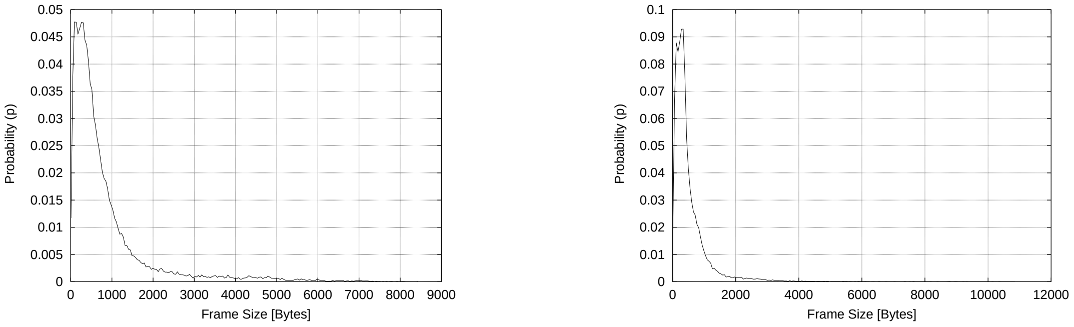
Encoding with rate control

Figure 2: GoP size Y_m^b as a function of the index m for the base layer of spatial scalable CIF video.



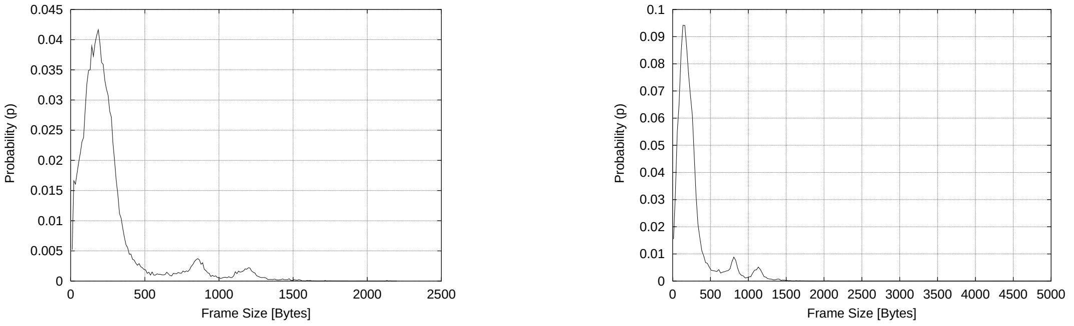
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



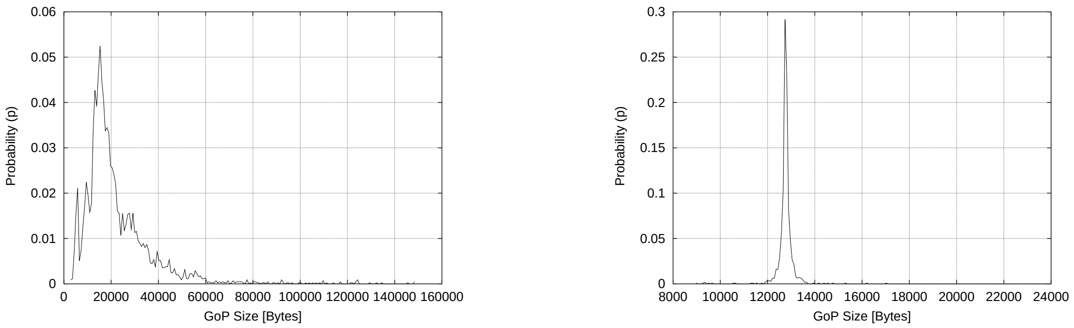
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

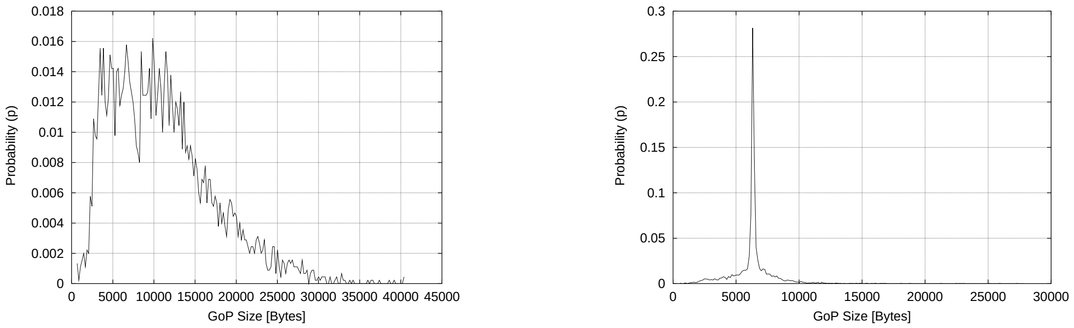
Encoding with rate control

Figure 3: Frame size histograms for the base layer of spatial scalable CIF video.



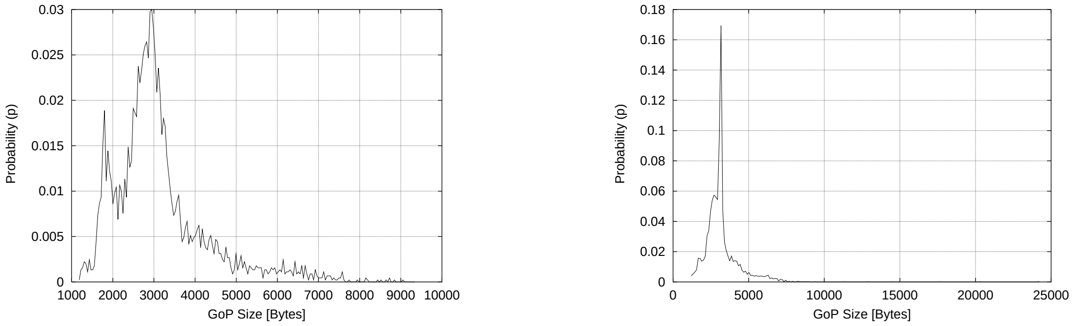
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



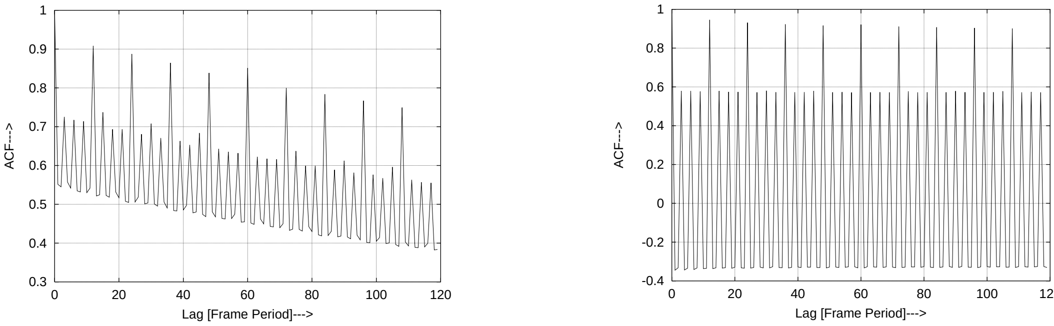
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

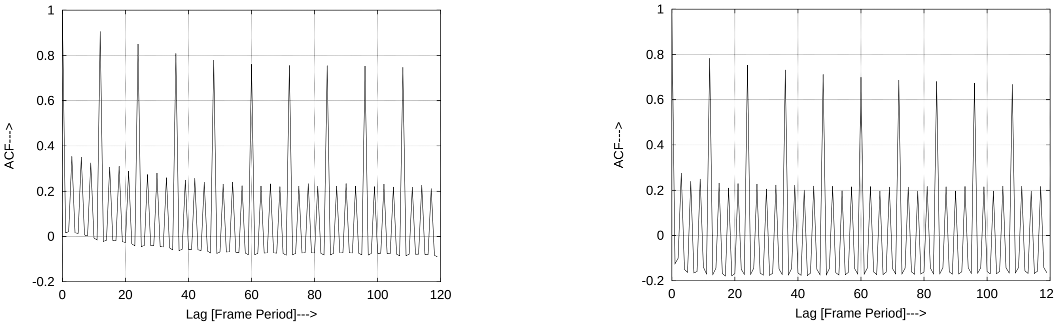
Encoding with rate control

Figure 4: GoP size histograms for the base layer of spatial scalable CIF video.



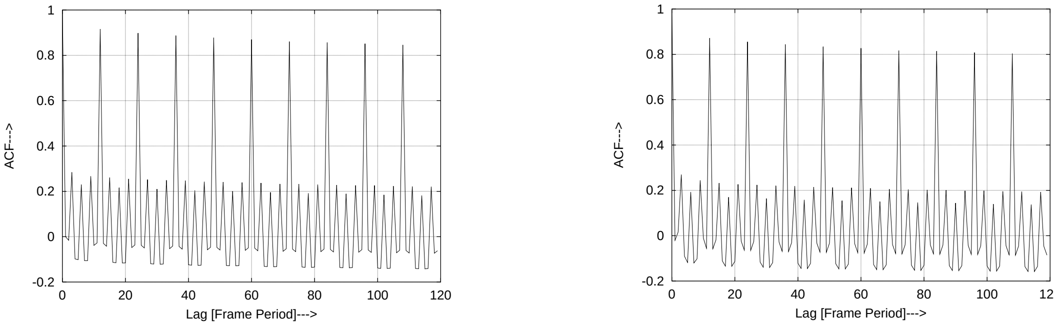
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



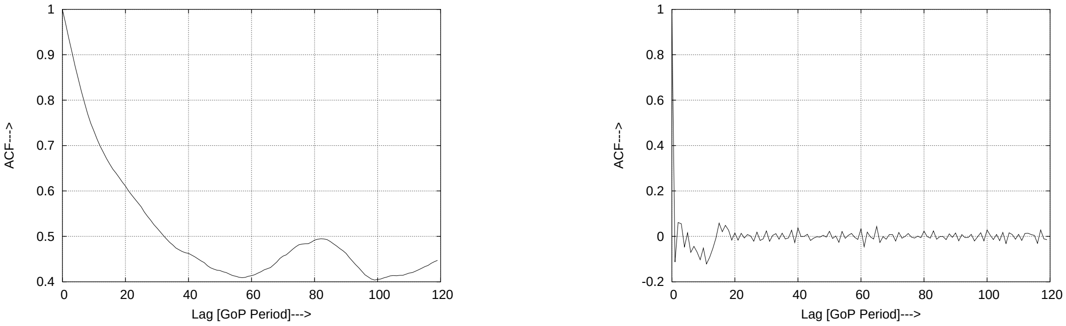
c) *Oprah w/o Comm* with low quality

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

Encoding without rate control

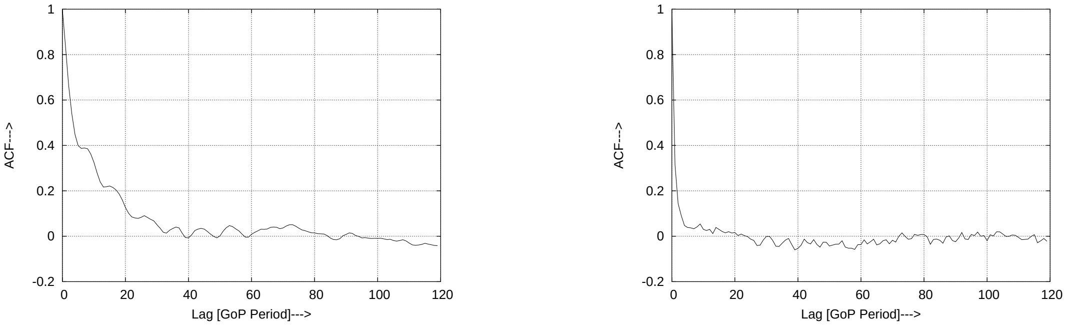
Encoding with rate control

Figure 5: Frame size autocorrelations for the base layer of spatial scalable CIF video.



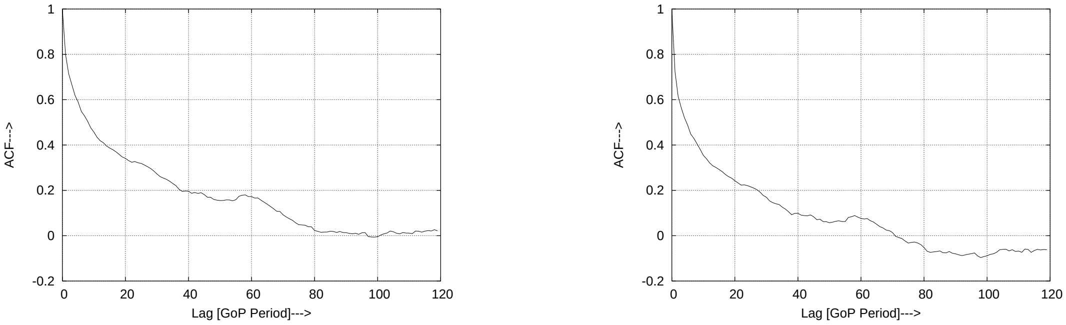
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



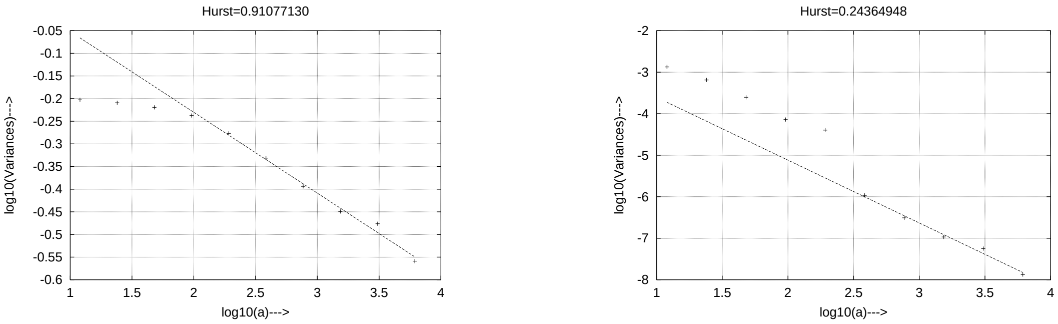
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

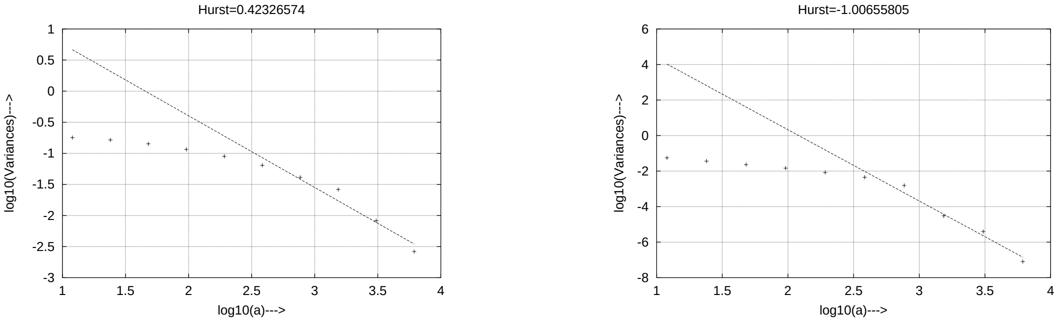
Encoding with rate control

Figure 6: GoP size correlations for the base layer of spatial scalable CIF video.



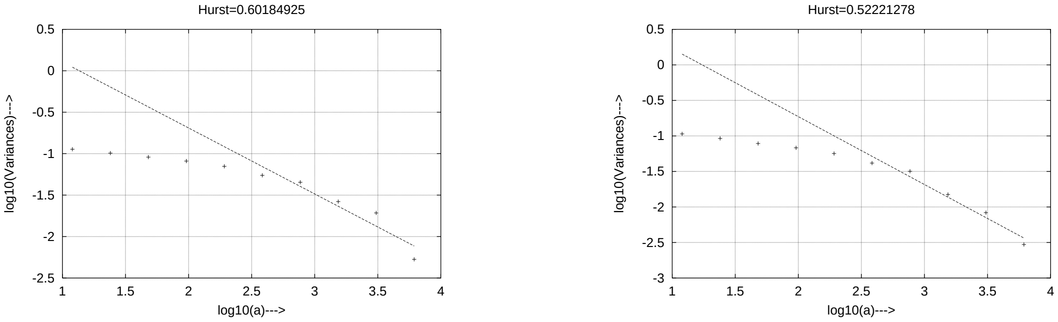
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



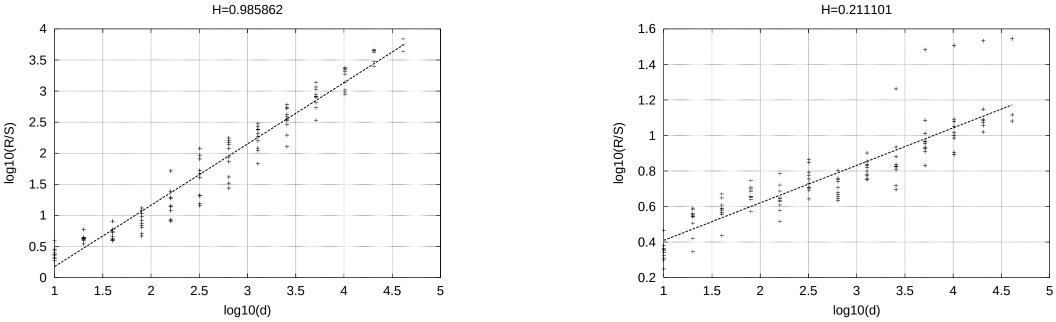
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

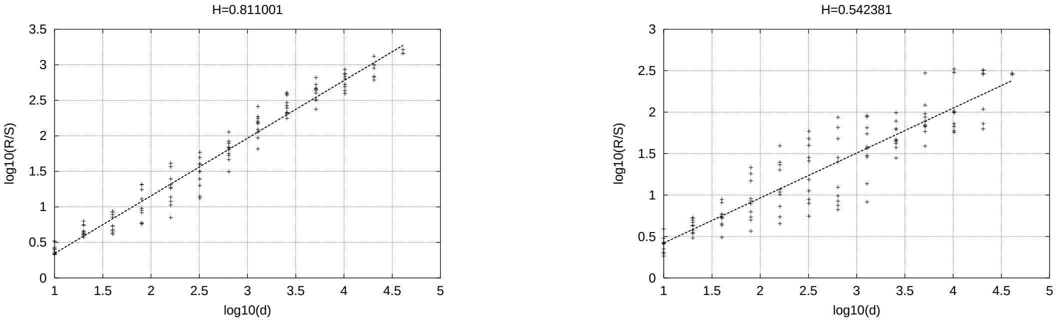
Encoding with rate control

Figure 7: Variance time plots for base layer of spatial scalable CIF video.



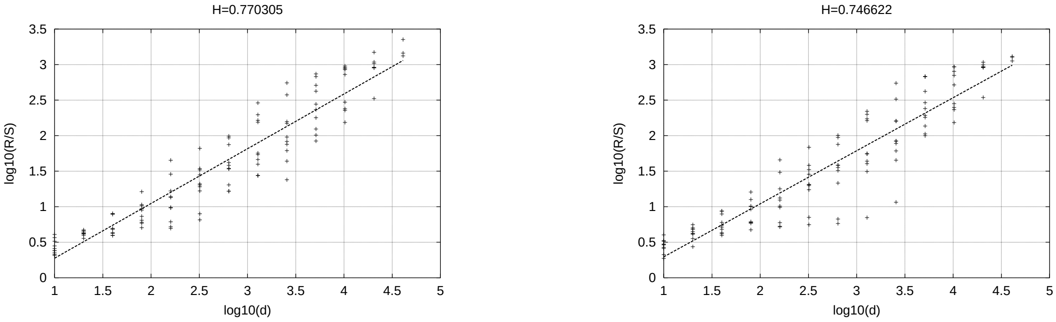
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



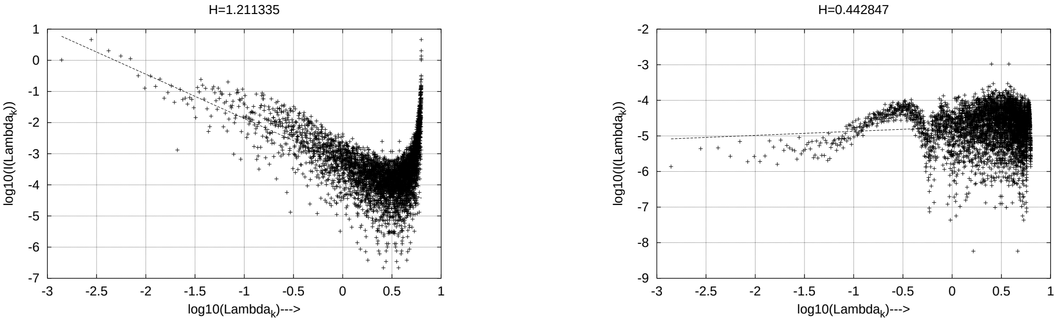
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

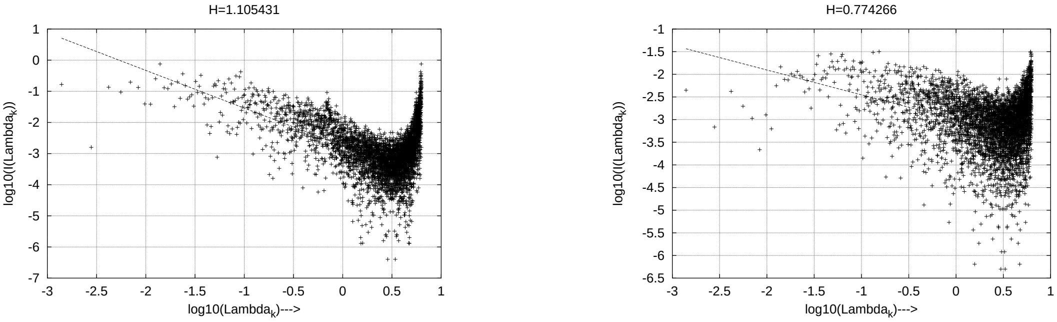
Encoding with rate control

Figure 8: Pox plots of R/S for aggregation level $a = 12$ for base layer of spatial scalable CIF video.



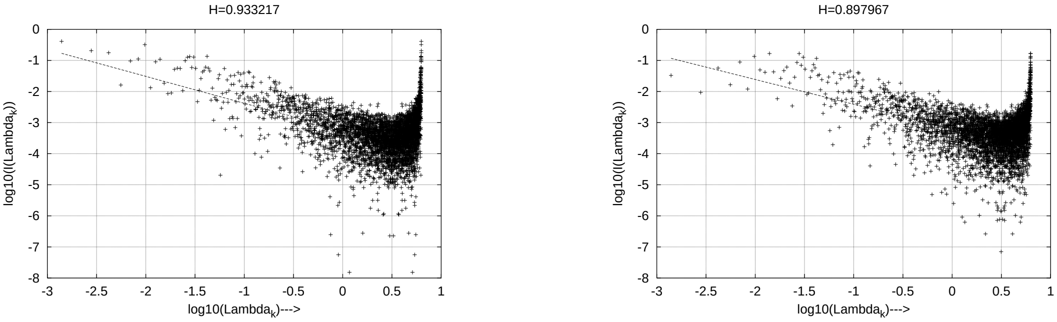
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



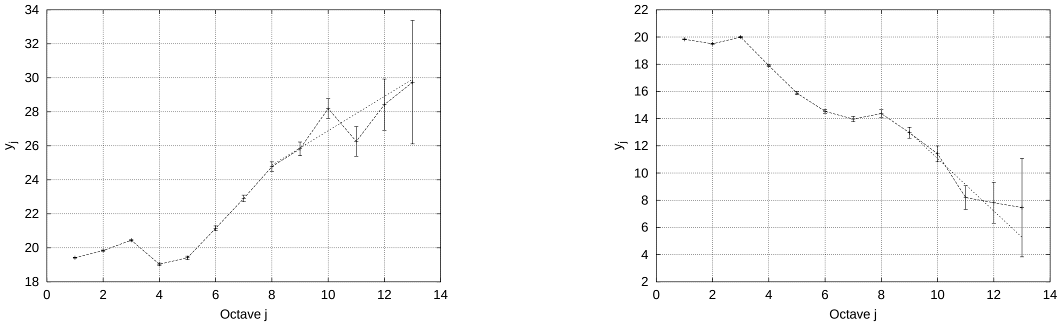
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

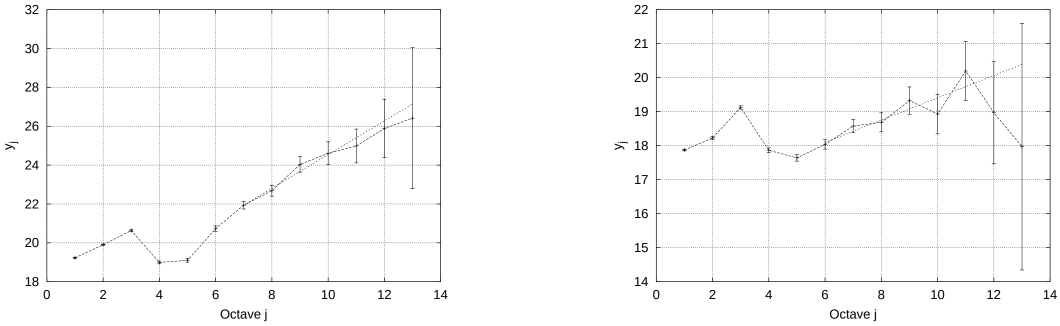
Encoding with rate control

Figure 9: Periodogram for aggregation level $a = 12$ for base layer of spatial scalable CIF video.



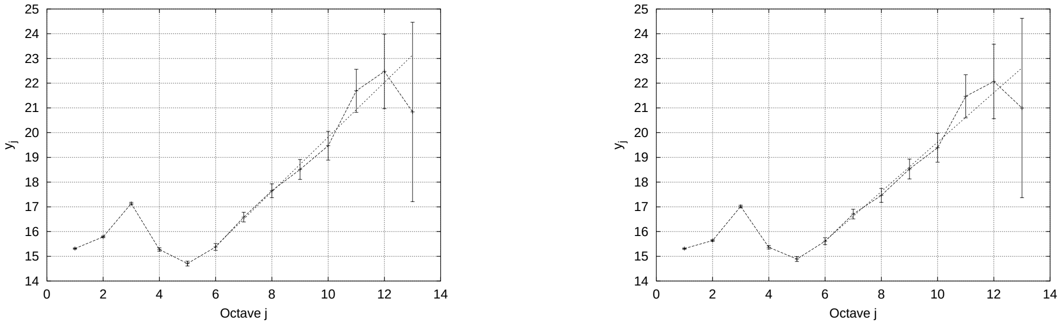
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



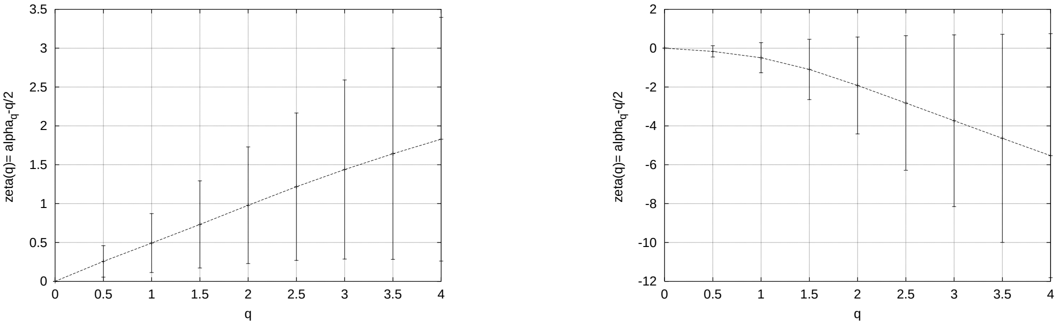
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

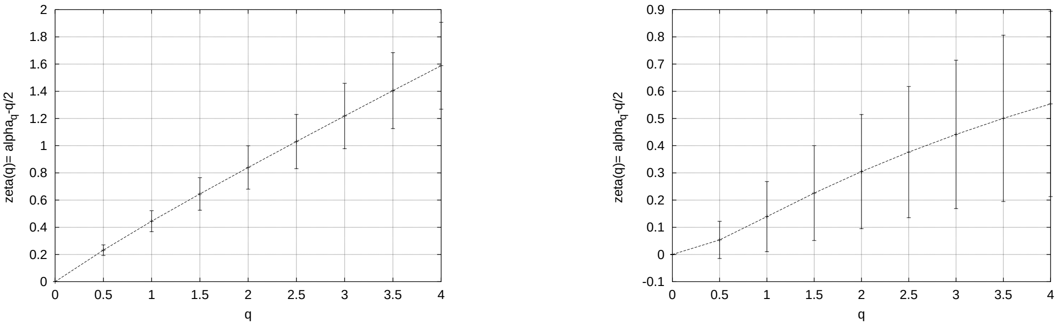
Encoding with rate control

Figure 10: Logscale diagrams for base layer of spatial scalable CIF video.



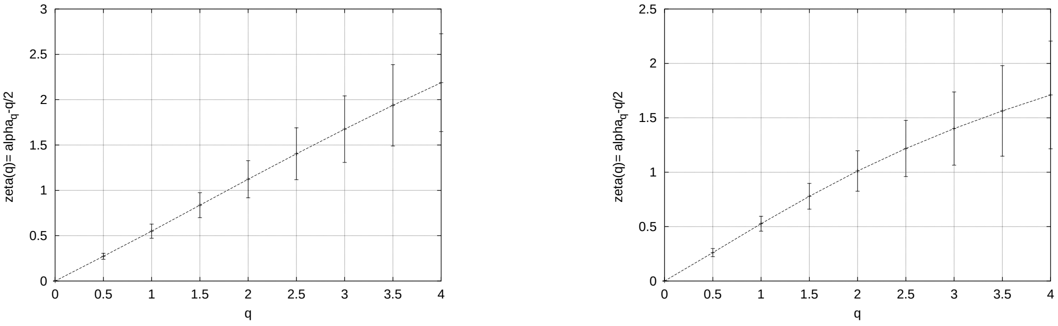
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



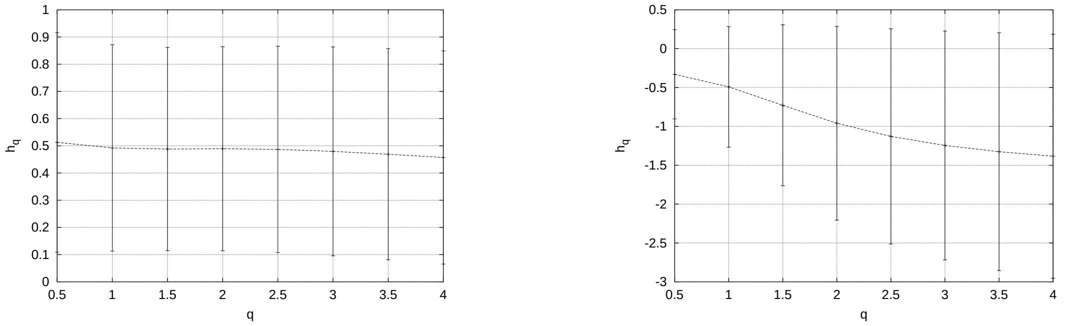
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

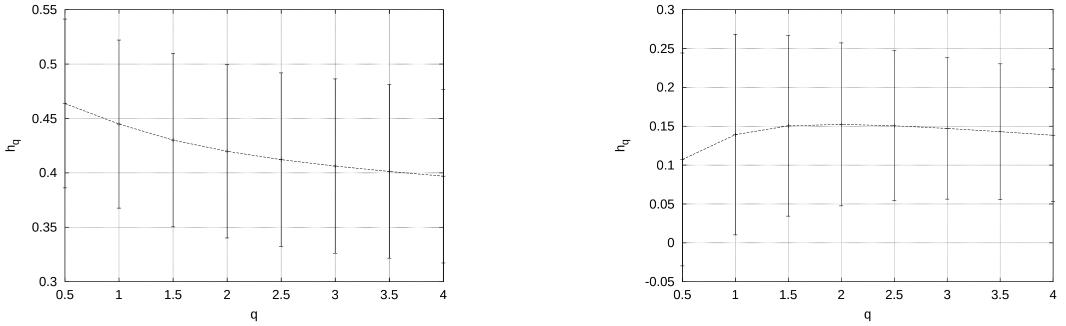
Encoding with rate control

Figure 11: Multiscale diagrams for base layer of spatial scalable CIF video.



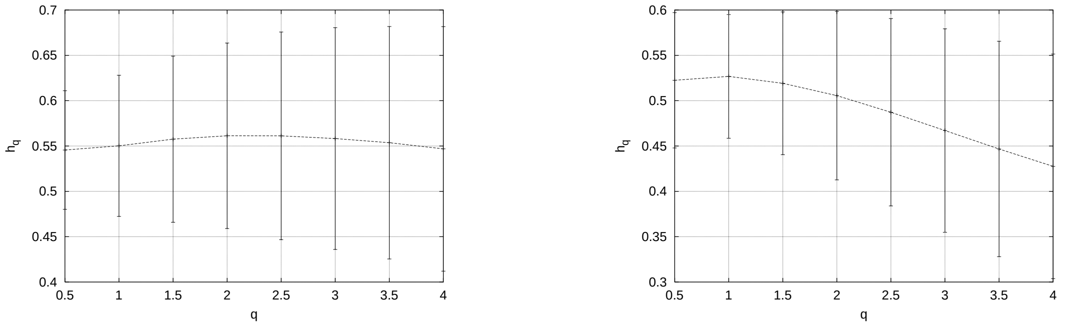
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



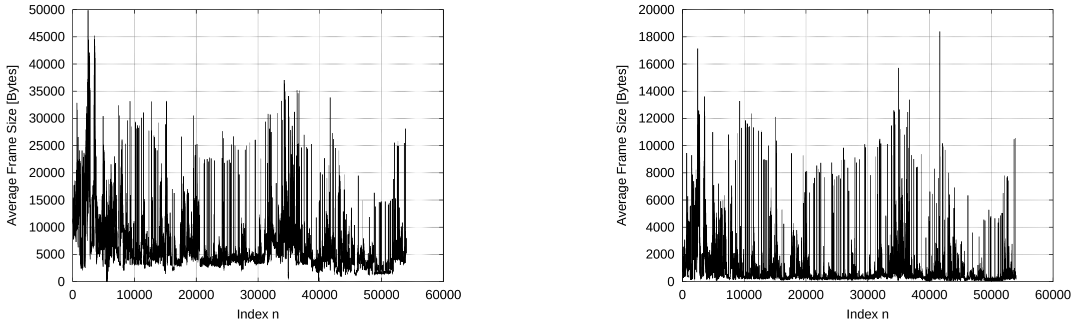
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

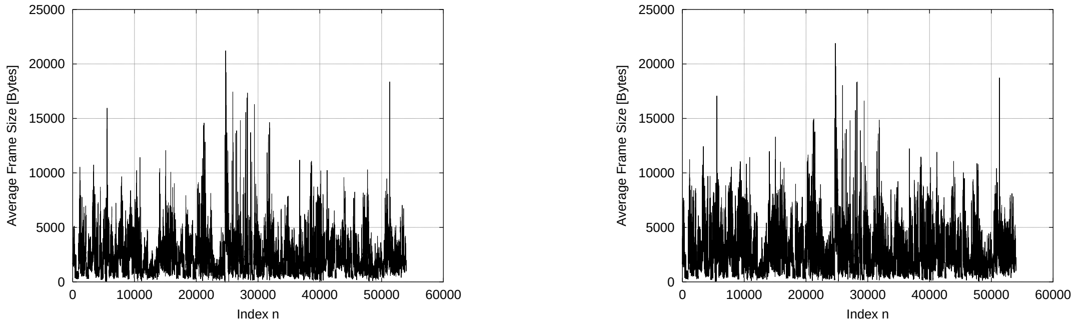
Encoding with rate control

Figure 12: Linear multiscale diagrams for base layer of spatial scalable CIF video.



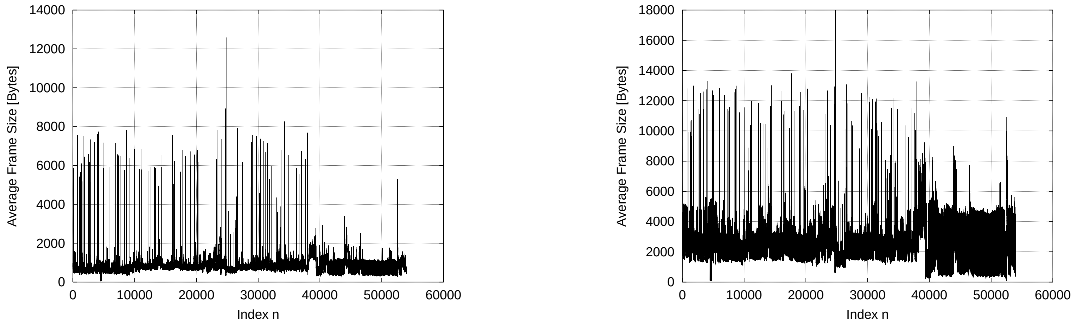
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



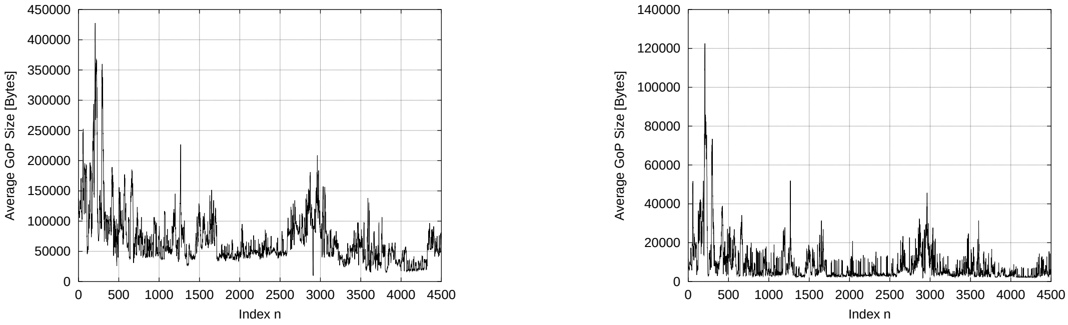
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

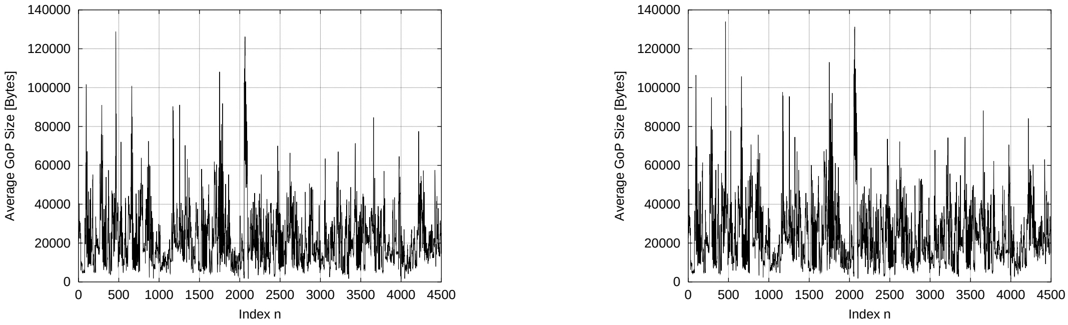
Encoding with rate control

Figure 13: Enhancement layer frame size X_n^e as a function of the frame index n for spatial scalable CIF video.



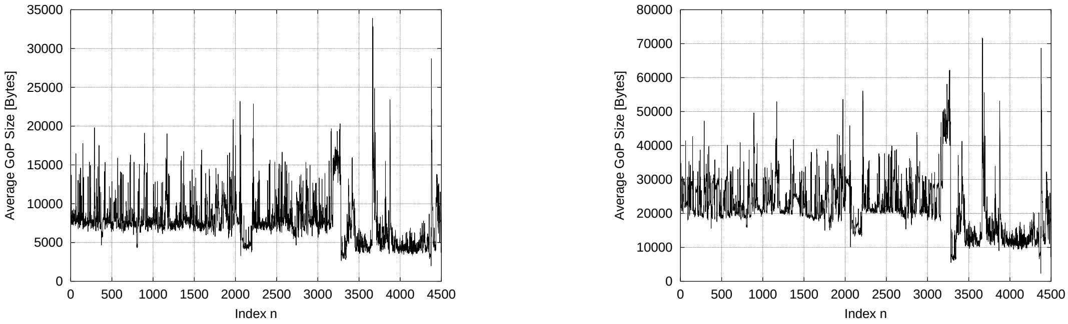
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



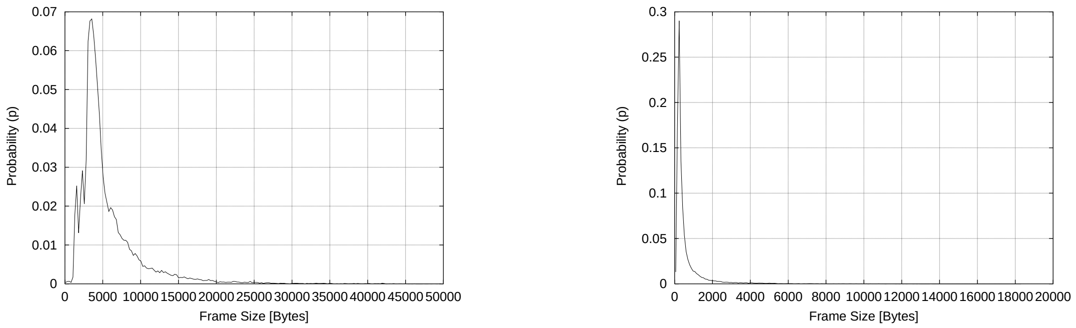
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

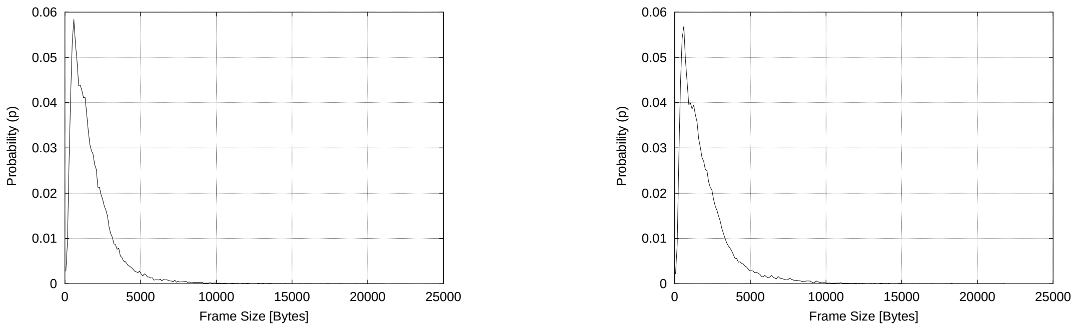
Encoding with rate control

Figure 14: GoP size Y_m^e as a function of the index m for spatial scalable CIF video.



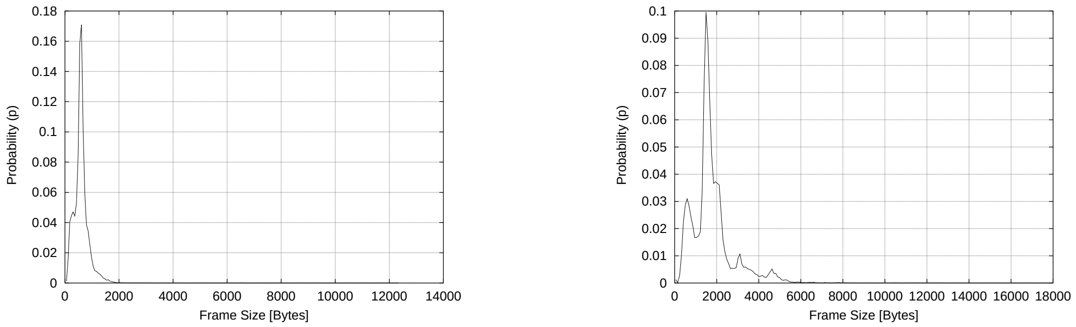
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



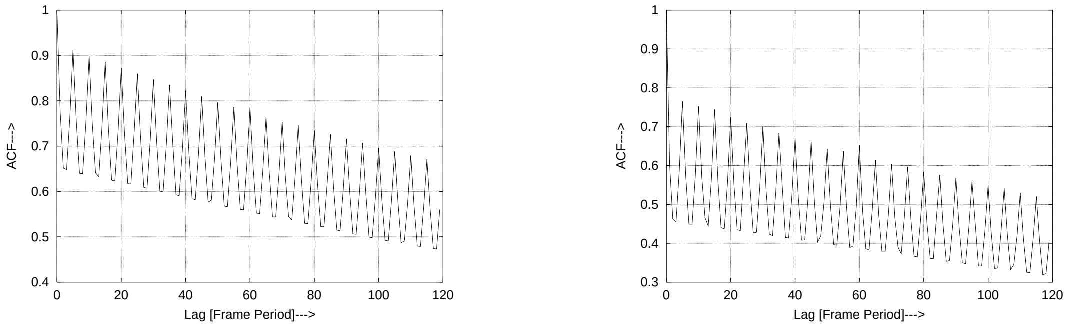
b) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

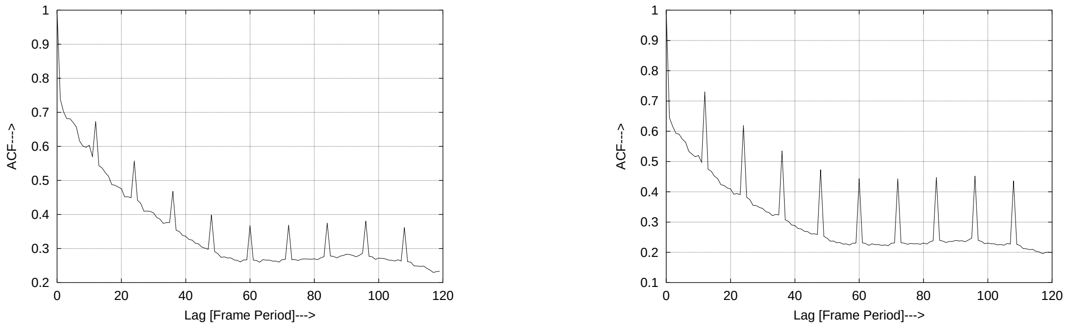
Encoding with rate control

Figure 15: Frame size histograms for the enhancement layer of spatial scalable CIF video.



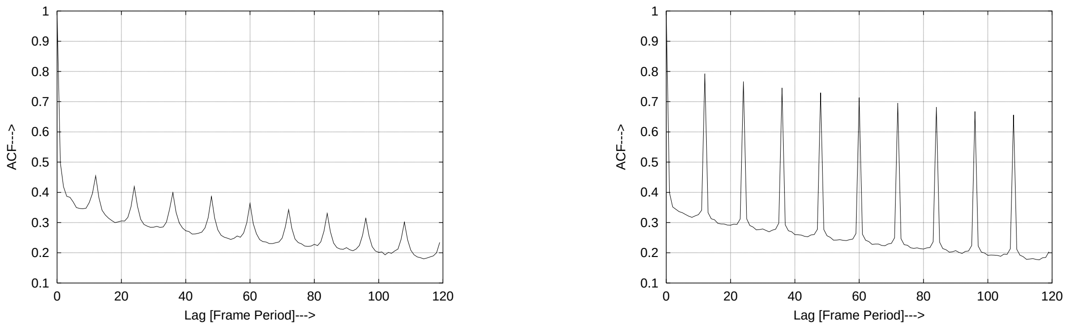
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



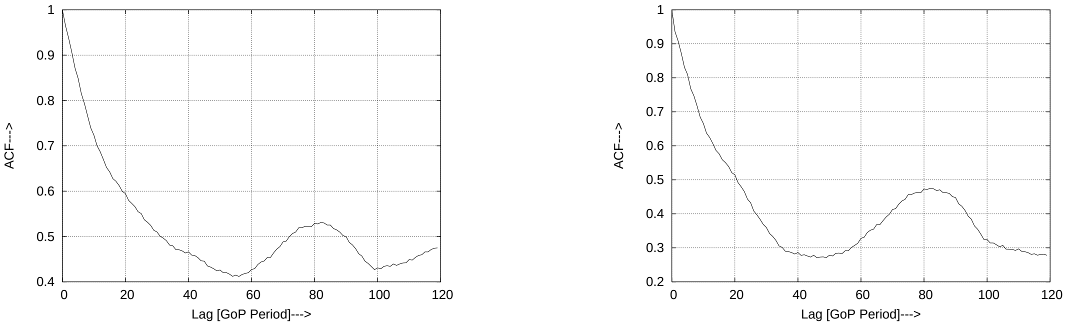
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

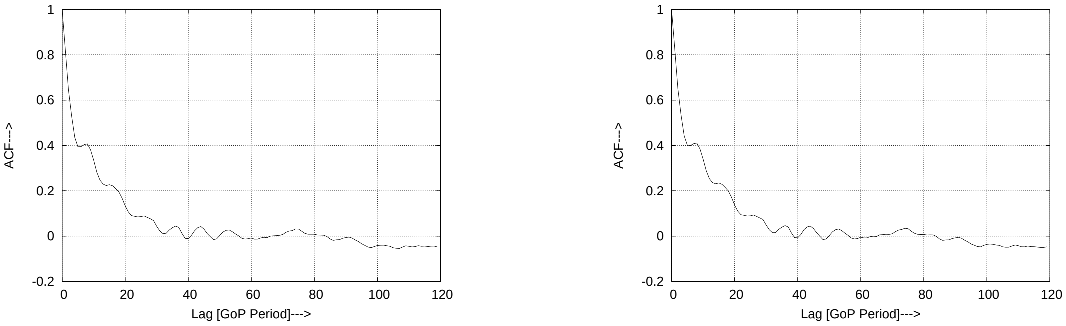
Encoding with rate control

Figure 16: Frame size autocorrelations for the enhancement layer of spatial scalable CIF video.



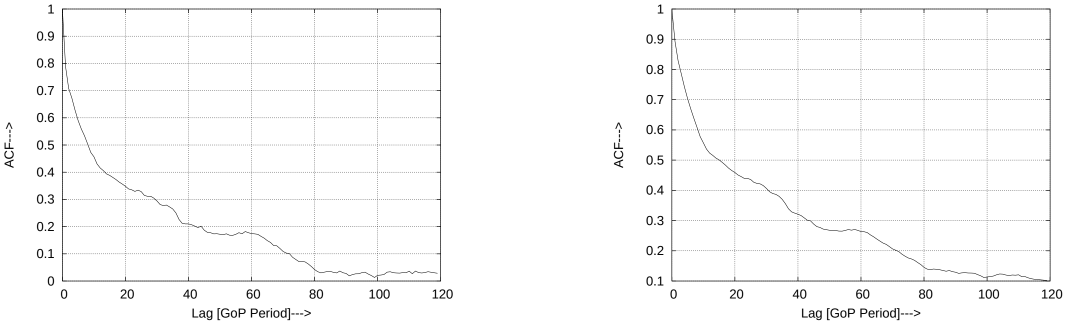
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



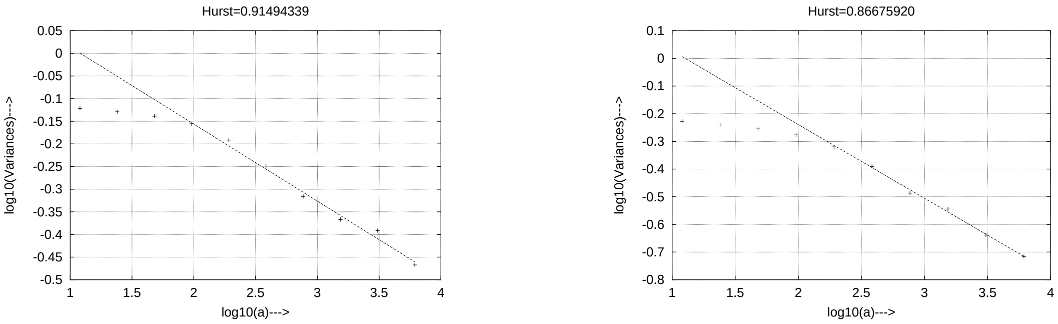
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

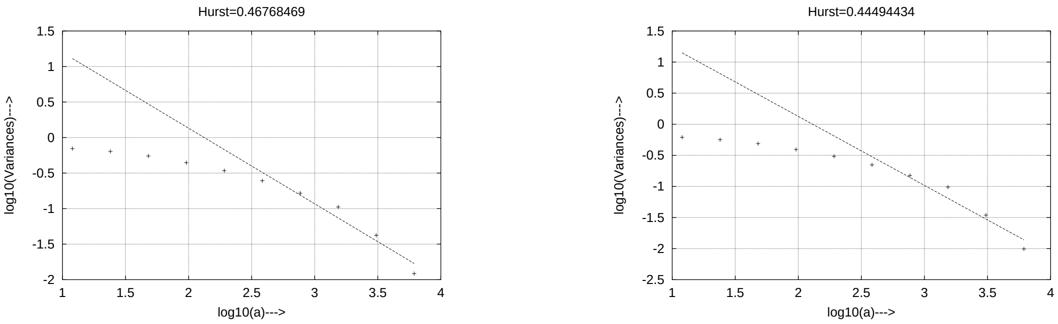
Encoding without rate control

Encoding with rate control

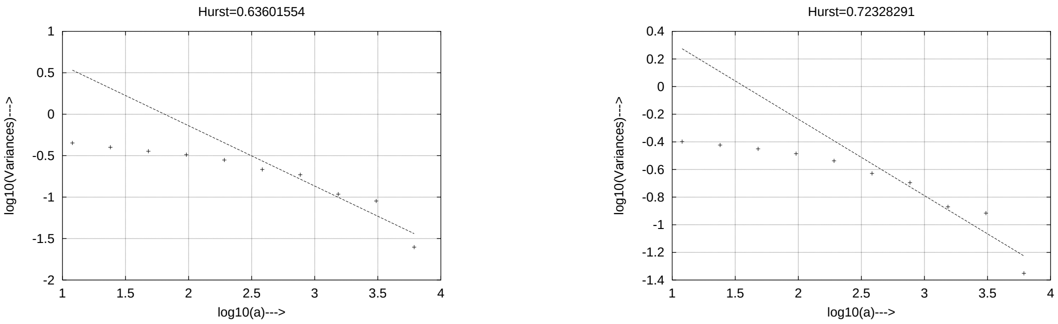
Figure 17: GoP size correlations for the enhancement layer of spatial scalable CIF video.



a) *Silence of the Lambs* with high quality d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality e) *Snowboard with Comm* with 128 kbps target bit rate



c) *Oprah w/o Comm* with low quality f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

Figure 18: Variance time plots for enhancement layer of spatial scalable CIF video.

Figure 21 gives the logscale diagrams.

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 spatial scalable encoded video. We estimate the covariance between base layer and enhancement layer at the frame level as

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

and the base-enhancement layer correlation coefficient as

$$\rho_{be} = \frac{S_{be}}{S_X^b \cdot S_X^e}. \tag{2}$$

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 ratio, mean frame size $\bar{X}$, the coefficient of variation CoV_X, the peak-to-mean ratio $X_{\max}/\bar{X}$, along with the bit rates and the base-enhancement layer correlation coefficient ρ_{be} are reported in Table 11. Table 12 gives the corresponding statistics for single layer encodings.

For the videos encoded without rate control, we observe that the $X_{\max}/\bar{X}$ of the aggregated frame sizes increase as the quality of the encoded video decreases, lowest quality encodings exhibiting highest ratios. The coefficient of variation CoV_X has a double "hump". The peaks are located at 060810.Q and medium quality (corresponding to 101416 QP). We observed the same behavior of peak-to-mean ratio and coefficient of variation in single layer CIF encodings without rate control as discussed in Part2 of this technical report series.

For sequences encoded with rate control, we observe that CoV_X and $X_{\max}/\bar{X}$ decrease as the target bit rate increases, with the exception of *ParkingLot* sequence where the peak-to-mean ratio increases as the target bit rate increases.

Comparing the average frame size of various video sequences encoded without rate control for spatial scalable and single layer encodings we do not observe a consistent trend. However, we observe that spatial scalable encodings at high quality have larger frame sizes than their single layer counterparts (usually 14 to 33 percent larger). For low quality encodings we observe that the average frame sizes in spatial encodings are 5 to 30 percent smaller than that of the corresponding single layer encodings. For medium quality encodings we observe that in most cases, the spatial encodings have smaller average frame sizes when compared to single layer encodings. For rate control encodings (64, 128, and 256 kbps) we observe that spatial encodings have always higher average frame size than the single layer encodings (at these target bit rates rate control is not effective) this can range from 20 to 100 percent.

We observe that the base-enhancement layer correlation coefficient can be used to show how well matched the sizes of the base and enhancement layers are for a given encoding mode. For the high quality encoding of *Oprah without Comm* without rate control, the enhancement and base layers are more strongly correlated than they are for the medium and low quality encodings without rate control. This indicates that the sizes of the frames in the base and enhancement layers are closer in size for the high quality encodings than for the medium or low quality encodings. Similar observations can be made for other video sequence such as *LectureHQ-Reisslein* but for different quality levels.

Video sequences such as *Silence of the Lambs* and *Terminator I* give very small base-enhancement layer coefficients for all quality levels (without rate control) indicating that the base and enhancement layers frame sizes are not very closely related. As expected the base-enhancement layer coefficient is never negative for the listed encodings.

Table 11: Overview of frame-level statistics of aggregated spatial 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]	ρ_{be}
CIF	*Silence of the Lambs*	19.922	7.633	0.730	8.573	1.832	15.706	0.285
H.Q.	*Terminator One*	13.032	11.669	0.546	5.097	2.800	14.275	0.242
No.R.C.	*Snowboard with Comm*	8.117	18.733	0.394	4.422	4.496	19.880	0.390
	Oprah w/o Comm	6.782	22.421	0.264	2.282	5.381	12.278	0.991
	LectureHQ-Reisslein	18.075	8.413	0.463	5.243	2.019	10.585	0.220
	ParkingLot	6.402	23.754	0.412	3.681	5.701	20.983	0.993
CIF	*Silence of the Lambs*	55.880	2.721	1.213	17.946	0.653	11.721	0.547
040608.Q.	*Terminator One*	30.044	5.061	0.810	9.268	1.215	11.258	0.392
No.R.C.	*Snowboard with Comm*	20.426	7.445	0.689	6.972	1.787	12.458	0.218
	Oprah w/o Comm	19.265	7.893	0.526	4.777	1.894	9.050	0.138
	LectureHQ-Reisslein	49.381	3.079	1.158	10.801	0.739	7.983	0.948
	ParkingLot	14.523	10.470	0.751	6.034	2.513	15.162	0.385
CIF	*Silence of the Lambs*	78.984	1.925	1.275	19.772	0.462	9.136	0.548
060810.Q.	*Terminator One*	40.461	3.758	0.839	9.865	0.902	8.898	0.360
No.R.C.	*Snowboard with Comm*	29.076	5.230	0.735	7.615	1.255	9.558	0.698
	Oprah w/o Comm	29.684	5.123	0.554	5.635	1.229	6.928	0.584
	LectureHQ-Reisslein	81.375	1.869	1.318	13.399	0.448	6.009	0.805
	ParkingLot	23.198	6.555	0.877	7.675	1.573	12.074	0.705
CIF	*Silence of the Lambs*	80.907	1.880	1.165	16.070	0.451	7.249	0.617
H.M.Q.	*Terminator One*	41.712	3.646	0.769	9.124	0.875	7.983	0.381
No.R.C.	*Snowboard with Comm*	30.728	4.949	0.653	7.392	1.188	8.780	0.743
	Oprah w/o Comm	31.655	4.804	0.428	4.956	1.153	5.714	0.555
	LectureHQ-Reisslein	73.123	2.080	0.902	11.994	0.499	5.986	0.916
	ParkingLot	21.013	7.237	0.690	5.626	1.737	9.771	0.287
CIF	*Silence of the Lambs*	143.742	1.058	1.303	22.175	0.254	5.630	0.449
M.Q.	*Terminator One*	71.245	2.134	0.904	11.650	0.512	5.968	0.259
No.R.C.	*Snowboard with Comm*	57.319	2.653	0.837	9.565	0.637	6.090	0.600

Table 11: *continued*

	Oprah w/o Comm	67.807	2.243	0.648	8.212	0.538	4.420	0.332
	LectureHQ-Reisslein	138.452	1.098	1.370	16.176	0.264	4.264	0.916
	ParkingLot	39.057	3.893	0.927	8.134	0.934	7.601	0.793
CIF	*Silence of the Lambs*	203.473	0.747	1.045	19.949	0.179	3.578	0.491
M.L.Q.	*Terminator One*	107.907	1.409	0.850	14.021	0.338	4.742	0.289
No.R.C.	*Snowboard with Comm*	95.959	1.585	0.756	11.624	0.380	4.421	0.605
	Oprah w/o Comm	124.219	1.224	0.551	12.124	0.294	3.562	0.369
	LectureHQ-Reisslein	217.943	0.698	1.013	19.727	0.167	3.303	0.828
	ParkingLot	70.044	2.171	0.852	8.340	0.521	4.345	0.803
CIF	*Silence of the Lambs*	232.563	0.654	0.913	20.367	0.157	3.196	0.455
L.Q.	*Terminator One*	130.674	1.164	0.826	14.942	0.279	4.173	0.274
No.R.C.	*Snowboard with Comm*	121.744	1.249	0.728	12.666	0.300	3.797	0.567
	Oprah w/o Comm	165.385	0.919	0.558	13.767	0.221	3.038	0.332
	LectureHQ-Reisslein	264.618	0.575	0.912	21.171	0.138	2.920	0.763
	ParkingLot	94.298	1.613	0.846	8.906	0.387	3.447	0.774
CIF	*Silence of the Lambs*	137.371	1.107	1.159	17.688	0.266	4.699	0.330
64 kbps	*Terminator One*	72.751	2.090	0.863	11.723	0.502	5.881	0.496
R.C.	*Snowboard with Comm*	62.586	2.430	0.805	9.702	0.583	5.657	0.772
	Oprah w/o Comm	72.183	2.107	0.598	8.666	0.506	4.381	0.697
	LectureHQ-Reisslein	145.789	1.043	1.338	17.210	0.250	4.308	0.760
	ParkingLot	44.361	3.428	0.896	8.139	0.823	6.696	0.910
CIF	*Silence of the Lambs*	120.093	1.266	1.026	15.463	0.304	4.699	0.102
128 kbps	*Terminator One*	70.542	2.156	0.837	11.430	0.517	5.914	0.126
R.C.	*Snowboard with Comm*	60.294	2.522	0.773	9.346	0.605	5.657	0.381
	Oprah w/o Comm	70.118	2.169	0.581	8.329	0.520	4.335	0.302
	LectureHQ-Reisslein	122.842	1.238	1.263	14.509	0.297	4.311	0.804
	ParkingLot	43.452	3.500	0.884	8.260	0.840	6.937	0.569
CIF	*Silence of the Lambs*	87.219	1.743	0.828	11.251	0.418	4.708	0.038
256 kbps	*Terminator One*	60.847	2.499	0.774	10.693	0.600	6.414	0.025
R.C.	*Snowboard with Comm*	52.531	2.895	0.704	8.300	0.695	5.766	0.232
	Oprah w/o Comm	60.830	2.500	0.568	7.355	0.600	4.413	0.141
	LectureHQ-Reisslein	86.589	1.756	1.069	10.162	0.421	4.283	0.754
	ParkingLot	39.351	3.864	0.855	9.094	0.927	8.434	0.436

Table 12: Overview of frame statistics of single-layer traces

		Compr.	Frame Size			Bit Rate	
		ratio	Mean	CoV_X	Peak/Mean	Mean	Peak
Enc. M.	Video	YUV:MP4	$\bar{X}$ [kbyte]	$S_X/\bar{X}$	$X_{\max}/\bar{X}$	$\bar{X}/T$ [Mbps]	$X_{\max}/T$ [Mbps]
QCIF	*Citizen Kane*	19.965	1.904	0.842	8.735	0.457	3.992
H. Q.	*Die Hard I*	13.721	2.771	0.518	4.675	0.665	3.108
No R.C.	*Jurassic Park I*	11.632	3.268	0.660	5.949	0.784	4.666
	Silence of the Lambs	20.208	1.881	0.774	8.721	0.451	3.937
	Star Wars IV	16.524	2.301	0.609	7.615	0.552	4.204
	Star Wars V	11.016	3.451	0.533	4.608	0.828	3.816
	The Firm	14.706	2.585	0.666	6.812	0.620	4.227
	Terminator I	12.959	2.934	0.624	8.318	0.704	5.856
	Total Recall	13.329	2.852	0.548	5.411	0.685	3.704
	Aladdin	6.934	5.483	0.403	4.115	1.316	5.414
	Cinderella	9.856	3.857	0.527	6.816	0.926	6.310
	Baseball with Comm	9.219	4.123	0.399	4.368	0.990	4.323
	Snowboard with Comm	8.076	4.707	0.477	5.494	1.130	6.207
	Oprah w/o Comm	6.784	5.604	0.395	2.993	1.345	4.025
	Tonight Show w/o Comm	13.868	2.741	0.881	7.230	0.658	4.757
	Lecture–Gupta	7.331	5.186	0.314	3.272	1.245	4.072
	Lecture–Reisslein	6.713	5.663	0.430	4.886	1.359	6.641
QCIF	*Jurassic Park I*	40.040	0.949	1.017	9.345	0.228	2.130
H.–M.Q.	*Star Wars IV*	62.028	0.613	1.037	16.303	0.147	2.398
No R.C.	*The Firm*	56.797	0.669	1.168	12.015	0.161	1.930
	Tonight Show w/o Comm	52.844	0.719	1.360	13.611	0.173	2.350
QCIF	*Citizen Kane*	96.556	0.394	1.786	21.350	0.094	2.017
M.Q.	*Die Hard I*	75.038	0.507	1.335	13.614	0.122	1.655
No R.C.	*Jurassic Park I*	64.456	0.590	1.562	15.044	0.142	2.130
	Silence of the Lambs	114.211	0.333	1.663	25.386	0.080	2.028
	Star Wars IV	91.976	0.413	1.488	24.175	0.099	2.398
	Star Wars V	73.775	0.515	1.493	13.914	0.124	1.721
	The Firm	88.192	0.431	1.724	17.784	0.103	1.840
	Terminator I	61.267	0.620	1.262	11.873	0.149	1.768
	Total Recall	75.298	0.505	1.400	13.088	0.121	1.586
	Aladdin	43.479	0.874	1.217	10.688	0.210	2.243
	Cinderella	59.663	0.637	1.336	17.708	0.153	2.708
	Baseball with Comm	63.021	0.603	1.285	12.846	0.145	1.860
	Snowboard with Comm	45.592	0.834	1.173	12.847	0.200	2.571
	Oprah w/o Comm	49.961	0.761	1.322	10.001	0.183	1.826
	Tonight Show w/o Comm	86.674	0.439	2.128	20.022	0.105	2.108
	Lecture–Gupta	50.257	0.756	1.398	12.218	0.182	2.218
	Lecture–Reisslein	47.219	0.805	1.376	12.741	0.193	2.462
QCIF	*Jurassic Park I*	116.295	0.327	1.085	11.466	0.078	0.900
M.–L.Q.	*Star Wars IV*	139.591	0.272	1.033	19.468	0.065	1.272
No R.C.	*The Firm*	145.542	0.261	1.159	12.358	0.063	0.775
	Tonight Show w/o Comm	164.978	0.230	1.547	18.461	0.055	1.021
QCIF	*Citizen Kane*	175.409	0.217	1.077	12.601	0.052	0.655
L.Q.	*Die Hard I*	129.899	0.293	0.844	9.147	0.070	0.642
No R.C.	*Jurassic Park I*	137.305	0.277	0.974	10.485	0.066	0.697
	Silence of the Lambs	177.651	0.214	0.873	13.356	0.051	0.686
	Star Wars IV	153.598	0.248	0.920	17.289	0.059	1.027
	Star Wars V	141.799	0.268	0.941	10.134	0.064	0.652
	The Firm	163.806	0.232	1.008	10.527	0.056	0.586
	Terminator I	116.748	0.326	0.842	10.610	0.078	0.829
	Total Recall	134.182	0.283	0.883	7.670	0.068	0.522
	Aladdin	100.523	0.378	0.916	8.702	0.091	0.790
	Cinderella	122.625	0.310	0.889	14.831	0.074	1.104
	Baseball with Comm	122.975	0.309	0.846	7.754	0.074	0.575
	Snowboard with Comm	97.017	0.392	0.820	8.662	0.094	0.815
	Oprah w/o Comm	133.957	0.284	0.959	8.351	0.068	0.569
	Tonight Show w/o Comm	196.206	0.194	1.374	17.228	0.047	0.801
	Lecture–Gupta	129.925	0.293	1.250	11.876	0.070	0.834
	Lecture–Reisslein	127.663	0.298	1.195	13.765	0.071	0.984

Table 12: *continued*

		Compr.	Frame Size			Bit Rate	
		ratio	Mean	CoV_X	Peak/Mean	Mean	Peak
Enc. M.	Video	YUV:MP4	$\bar{X}$ [kbyte]	$S_X/\bar{X}$	$X_{\max}/\bar{X}$	$\bar{X}/T$ [Mbps]	$X_{\max}/T$ [Mbps]
QCIF	*Citizen Kane*	142.259	0.267	1.328	64.435	0.064	4.133
R.C.	*Die Hard I*	131.009	0.290	0.833	12.203	0.070	0.850
64 kbps	*Jurassic Park I*	137.581	0.276	0.973	64.310	0.066	4.265
	Silence of the Lambs	142.253	0.267	1.118	67.003	0.064	4.297
	Star Wars IV	141.355	0.269	1.086	69.354	0.065	4.476
	Star Wars V	137.533	0.276	1.055	82.720	0.066	5.488
	The Firm	142.255	0.267	1.148	48.197	0.064	3.091
	Terminator I	116.602	0.326	0.861	53.645	0.078	4.198
	Total Recall	133.182	0.285	0.970	66.766	0.069	4.574
	Aladdin	102.525	0.371	0.918	60.114	0.089	5.350
	Cinderella	123.850	0.307	0.874	22.362	0.074	1.647
	Baseball with Comm	123.813	0.307	0.844	11.793	0.074	0.869
	Snowboard with Comm	99.000	0.384	0.806	8.398	0.092	0.774
	Oprah w/o Comm	136.007	0.280	1.023	93.701	0.067	6.286
	Tonight Show w/o Comm	140.998	0.270	1.494	45.286	0.065	2.930
	Lecture–Gupta	133.741	0.284	1.237	27.532	0.068	1.878
	Lecture–Reisslein	125.820	0.302	1.113	13.057	0.073	0.947
QCIF	*Citizen Kane*	71.206	0.534	1.401	17.749	0.128	2.274
R.C.	*Die Hard I*	71.204	0.534	1.169	20.918	0.128	2.680
128 kbps	*Jurassic Park I*	71.205	0.534	1.295	20.774	0.128	2.662
	Silence of the Lambs	71.206	0.534	1.117	33.430	0.128	4.284
	Star Wars IV	71.206	0.534	1.132	22.063	0.128	2.827
	Star Wars V	71.206	0.534	1.132	26.592	0.128	3.407
	The Firm	71.206	0.534	1.286	22.291	0.128	2.856
	Terminator I	71.086	0.535	1.130	31.122	0.128	3.995
	Total Recall	71.207	0.534	1.182	19.649	0.128	2.518
	Aladdin	71.206	0.534	1.066	50.883	0.128	6.520
	Cinderella	71.206	0.534	1.186	41.940	0.128	5.374
	Baseball with Comm	71.205	0.534	1.119	26.185	0.128	3.355
	Snowboard with Comm	71.207	0.534	1.077	39.932	0.128	5.117
	Oprah w/o Comm	71.206	0.534	1.211	15.679	0.128	2.009
	Tonight Show w/o Comm	71.206	0.534	1.358	20.366	0.128	2.610
	Lecture–Gupta	71.206	0.534	1.604	19.677	0.128	2.521
	Lecture–Reisslein	71.206	0.534	1.293	25.650	0.128	3.287
QCIF	*Citizen Kane*	35.622	1.067	1.102	11.164	0.256	2.859
R.C	*Die Hard I*	35.622	1.067	0.978	8.981	0.256	2.300
256 kbps	*Jurassic Park I*	35.622	1.067	1.106	9.345	0.256	2.394
	Silence of the Lambs	35.622	1.067	0.904	8.006	0.256	2.051
	Star Wars IV	35.622	1.067	0.927	9.659	0.256	2.474
	Star Wars V	35.622	1.067	0.961	6.890	0.256	1.765
	The Firm	35.621	1.067	1.046	10.775	0.256	2.760
	Terminator I	35.622	1.067	1.009	11.874	0.256	3.041
	Total Recall	35.622	1.067	1.001	8.991	0.256	2.303
	Aladdin	35.622	1.067	1.005	13.086	0.256	3.352
	Cinderella	35.622	1.067	1.010	10.049	0.256	2.574
	Baseball with Comm	35.622	1.067	0.924	10.565	0.256	2.706
	Snowboard with Comm	35.622	1.067	0.950	9.911	0.256	2.538
	Oprah w/o Comm	35.622	1.067	0.987	8.445	0.256	2.163
	Tonight Show w/o Comm	35.622	1.067	1.081	8.479	0.256	2.172
	Lecture–Gupta	35.621	1.067	1.090	9.192	0.256	2.354
	Lecture–Reisslein	35.622	1.067	0.989	7.426	0.256	1.902
CIF	*Silence of Lambs*	22.735	6.688	0.742	8.271	1.605	13.277
040404.	*Terminator I*	14.973	10.156	0.564	5.497	2.437	13.398
No.R.C.	*Snowboard with Comm*	9.908	15.348	0.402	4.455	3.684	16.411
	Oprah w/o Comm	7.890	19.274	0.311	3.355	4.626	15.521
	ParkingLot	8.528	17.832	0.450	4.150	4.280	17.760
	LectureHQ-Reisslein	23.689	6.419	0.553	6.263	1.541	9.649
CIF	*Silence of Lambs*	47.721	3.187	1.301	13.994	0.765	10.702
040608.	*Terminator I*	28.203	5.392	0.923	7.762	1.294	10.044

Table 12: *continued*

		Compr.	Frame Size			Bit Rate	
		ratio	Mean	CoV_X	Peak/Mean	Mean	Peak
Enc. M.	Video	YUV:MP4	$\bar{X}$ [kbyte]	$S_X/\bar{X}$	$X_{\max}/\bar{X}$	$\bar{X}/T$ [Mbps]	$X_{\max}/T$ [Mbps]
No.R.C.	*Snowboard with Comm*	20.580	7.389	0.853	6.672	1.773	11.831
	Oprah w/o Comm	18.034	8.432	0.820	4.862	2.024	9.838
	ParkingLot	16.784	9.060	0.948	6.011	2.174	13.071
	LectureHQ-Reisslein	52.194	2.913	1.495	12.649	0.699	8.845
CIF	*Silence of Lambs*	71.161	2.137	1.345	16.123	0.513	8.269
060810.	*Terminator I*	38.703	3.929	0.926	8.710	0.943	8.213
No.R.C.	*Snowboard with Comm*	30.103	5.051	0.869	7.965	1.212	9.657
	Oprah w/o Comm	28.609	5.315	0.856	5.533	1.276	7.058
	ParkingLot	24.594	6.183	0.966	6.995	1.484	10.380
	LectureHQ-Reisslein	79.795	1.906	1.618	14.382	0.457	6.578
CIF	*Silence of Lambs*	83.051	1.831	1.181	14.506	0.439	6.374
101010.	*Terminator I*	43.964	3.459	0.806	8.754	0.830	7.267
No.R.C.	*Snowboard with Comm*	36.082	4.214	0.710	8.028	1.011	8.120
	Oprah w/o Comm	36.750	4.138	0.562	5.153	0.993	5.117
	ParkingLot	27.418	5.546	0.798	6.422	1.331	8.548
	LectureHQ-Reisslein	95.279	1.596	1.221	14.186	0.383	5.434
CIF	*Silence of Lambs*	116.402	1.306	1.326	18.782	0.314	5.889
101416.	*Terminator I*	63.308	2.402	0.970	10.581	0.576	6.100
No. R.C.	*Snowboard with Comm*	57.047	2.666	1.025	9.906	0.640	6.337
	Oprah w/o Comm	62.375	2.438	0.995	7.373	0.585	4.314
	ParkingLot	44.575	3.411	1.246	8.888	0.819	7.277
	LectureHQ-Reisslein	141.644	1.074	1.915	17.302	0.258	4.458
CIF	*Silence of Lambs*	153.029	0.994	0.916	13.957	0.238	3.329
242424.	*Terminator I*	92.405	1.646	0.790	11.693	0.395	4.618
No. R.C.	*Snowboard with Comm*	91.491	1.662	0.792	10.683	0.399	4.261
	Oprah w/o Comm	111.413	1.365	0.667	10.109	0.328	3.312
	ParkingLot	80.036	1.900	1.040	8.647	0.456	3.943
	LectureHQ-Reisslein	215.257	0.706	1.336	18.159	0.170	3.079
CIF	*Silence of Lambs*	160.877	0.945	0.774	13.009	0.227	2.951
303030.	*Terminator I*	105.134	1.446	0.733	11.748	0.347	4.078
No. R.C.	*Snowboard with Comm*	106.709	1.425	0.735	10.766	0.342	3.682
	Oprah w/o Comm	131.487	1.156	0.619	10.545	0.278	2.927
	ParkingLot	99.389	1.530	1.007	9.193	0.367	3.376
	LectureHQ-Reisslein	231.406	0.657	1.156	17.327	0.158	2.733
CIF	*Silence of Lambs*	162.275	0.937	0.762	12.901	0.225	2.901
R.C.	*Terminator I*	106.532	1.427	0.724	11.583	0.343	3.968
64kbps.	*Snowboard with Comm*	108.120	1.406	0.720	10.711	0.338	3.615
	Oprah w/o Comm	133.213	1.142	0.606	10.555	0.274	2.892
	ParkingLot	101.609	1.497	0.993	9.221	0.359	3.312
	LectureHQ-Reisslein	232.909	0.653	1.126	17.072	0.157	2.675
CIF	*Silence of Lambs*	162.251	0.937	0.763	12.899	0.225	2.901
R.C.	*Terminator I*	106.516	1.428	0.724	11.581	0.343	3.968
128kbps.	*Snowboard with Comm*	108.115	1.407	0.720	10.710	0.338	3.615
	Oprah w/o Comm	133.204	1.142	0.607	10.555	0.274	2.892
	ParkingLot	101.606	1.497	0.993	9.221	0.359	3.312
	LectureHQ-Reisslein	232.885	0.653	1.126	17.065	0.157	2.674
CIF	*Silence of Lambs*	137.562	1.105	0.933	49.493	0.265	13.131
R.C.	*Terminator I*	106.253	1.431	0.722	11.552	0.343	3.968
256kbps.	*Snowboard with Comm*	107.719	1.412	0.729	17.755	0.339	6.015
	Oprah w/o Comm	128.102	1.187	0.686	14.182	0.285	4.040
	ParkingLot	101.548	1.497	0.995	9.618	0.359	3.457
	LectureHQ-Reisslein	142.497	1.067	1.741	15.237	0.256	3.902
CIF	*ParkingLot*	71.228	2.135	1.612	28.175	0.512	14.436
R.C.	*LectureHQ-Reisslein*	71.264	2.134	1.210	9.465	0.512	4.847
512kbps							
CIF	*ParkingLot*	35.637	4.267	1.049	16.733	1.024	17.136
R.C.	*LectureHQ-Reisslein*	35.636	4.267	0.837	6.665	1.024	6.825
1024kbps							

Table 13 gives the mean GoP size ($\bar{Y}$), the GoP coefficient of variation (CoV_Y), the GoP peak-to-mean ratio ($Y_{\max}/\bar{Y}$), along with the peak bit rate ($Y_{\max}/(GT)$) and the GoP level base-enhancement layer correlation coefficient (ρ_{be}^{G}). The observations made earlier for Table 11 can be extended here with a few exceptions.

We observe the that CoV_Y exhibits a hump which is centered somewhere near the medium quality as was observed in other tables. The CoV_Y and $Y_{\max}/(GT)$ are smaller than corresponding CoV_X and $X_{\max}/(GT)$ because of the aggregation.

We observe that the base-enhancement layer coefficient is always high at the GoP aggregation level in all the video sequences for encodings without rate control indicating a strong base GoP size and enhancement layer GoP size correlation. We further observe that for encodings with rate control, this correlation is very small and even negative for a target bit rate of 256 kbps (actually correlation decreases with increasing target bit rate). This is because the base layer is encoded in QCIF format with rate control being very effective at 128 kbps and 256 kbps whereas enhancement layer is encoded without rate control. This leads to a lower base-enhancement layer correlations.

Table 13: Overview of GoP–level statistics of aggregated spatial 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]	$\rho_{be}^{(G)}$
CIF	*Silence of the Lambs*	91.597	0.656	6.338	11.611	0.982
H.Q.	*Terminator One*	140.024	0.424	2.747	7.693	0.966
No.R.C.	*Snowboard with Comm*	224.798	0.359	2.774	12.473	0.947
	Oprah w/o Comm	269.052	0.248	1.889	10.167	0.984
	LectureHQ-Reisslein	100.953	0.235	2.866	5.786	0.952
	ParkingLot	285.052	0.346	2.811	16.023	0.978
CIF	*Silence of the Lambs*	32.655	0.925	9.885	6.456	0.968
040608.Q.	*Terminator One*	60.737	0.502	3.144	3.819	0.932
No.R.C.	*Snowboard with Comm*	89.336	0.493	3.809	6.805	0.929
	Oprah w/o Comm	94.721	0.318	2.455	4.652	0.972
	LectureHQ-Reisslein	36.953	0.303	3.652	2.699	0.966
	ParkingLot	125.644	0.493	3.712	9.329	0.983
CIF	*Silence of the Lambs*	23.103	0.990	11.026	5.095	0.965
060810.Q.	*Terminator One*	45.100	0.523	3.230	2.914	0.920
No.R.C.	*Snowboard with Comm*	62.758	0.543	4.294	5.389	0.920
	Oprah w/o Comm	61.474	0.345	2.714	3.337	0.965
	LectureHQ-Reisslein	22.424	0.419	4.454	1.998	0.588
	ParkingLot	78.662	0.622	4.789	7.534	0.753
CIF	*Silence of the Lambs*	22.554	0.975	10.839	4.889	0.968
H.M.Q.	*Terminator One*	43.747	0.519	3.196	2.796	0.927
No.R.C.	*Snowboard with Comm*	59.384	0.552	4.375	5.196	0.924
	Oprah w/o Comm	57.645	0.345	2.749	3.170	0.967
	LectureHQ-Reisslein	24.955	0.318	3.844	1.919	0.966
	ParkingLot	86.840	0.546	4.179	7.258	0.984
CIF	*Silence of the Lambs*	12.695	0.992	11.981	3.042	0.959
M.Q.	*Terminator One*	25.613	0.545	3.465	1.775	0.903
No.R.C.	*Snowboard with Comm*	31.835	0.605	5.105	3.250	0.897
	Oprah w/o Comm	26.911	0.379	3.239	1.743	0.950
	LectureHQ-Reisslein	13.180	0.330	3.971	1.047	0.911
	ParkingLot	46.721	0.620	5.031	4.701	0.981
CIF	*Silence of the Lambs*	8.968	0.823	10.299	1.847	0.959
M.L.Q.	*Terminator One*	16.911	0.527	3.489	1.180	0.914
No.R.C.	*Snowboard with Comm*	19.016	0.586	5.302	2.017	0.900
	Oprah w/o Comm	14.690	0.363	3.528	1.037	0.928
	LectureHQ-Reisslein	8.373	0.281	3.761	0.630	0.944
	ParkingLot	26.052	0.628	5.668	2.953	0.983
CIF	*Silence of the Lambs*	7.846	0.714	8.990	1.411	0.951
L.Q.	*Terminator One*	13.964	0.509	3.483	0.973	0.907
No.R.C.	*Snowboard with Comm*	14.989	0.559	5.184	1.554	0.900
	Oprah w/o Comm	11.033	0.354	3.710	0.819	0.915
	LectureHQ-Reisslein	6.896	0.248	3.549	0.489	0.922
	ParkingLot	19.351	0.616	5.925	2.293	0.984
CIF	*Silence of the Lambs*	13.284	0.875	10.565	2.807	0.700
64 kbps	*Terminator One*	25.083	0.532	3.494	1.753	0.911

Table 13: *continued*

R.C.	*Snowboard with Comm*	29.156	0.583	5.031	2.934	0.905
	Oprah w/o Comm	25.280	0.349	3.108	1.571	0.679
	LectureHQ-Reisslein	12.517	0.291	3.800	0.951	0.278
	ParkingLot	41.134	0.603	5.179	4.260	0.977
CIF 128 kbps R.C.	*Silence of the Lambs*	15.195	0.712	9.236	2.807	0.314
	Terminator One	25.868	0.488	3.388	1.753	0.199
	Snowboard with Comm	30.264	0.539	4.847	2.934	0.405
	Oprah w/o Comm	26.024	0.330	3.027	1.576	0.101
	LectureHQ-Reisslein	14.855	0.217	3.243	0.964	0.047
	ParkingLot	41.995	0.578	5.099	4.282	0.634
CIF 256 kbps R.C.	*Silence of the Lambs*	20.922	0.465	6.710	2.808	0.006
	Terminator One	29.989	0.378	2.919	1.751	-0.005
	Snowboard with Comm	34.737	0.439	4.274	2.969	0.005
	Oprah w/o Comm	29.998	0.266	2.711	1.627	-0.046
	LectureHQ-Reisslein	21.074	0.140	2.407	1.015	-0.035
	ParkingLot	46.371	0.481	4.777	4.430	-0.077

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 14 gives the average quality ($\bar{Q}^b$), the coefficient of quality variation ($CoQV^b$), and the quality range ($Q_{\min}^{\max,b}$) for the decoded base layer stream. The quality statistics are provided for the frame level and the GoP level. In spatial encodings, the base layer is obtained by spatially down-sampling the CIF video sequence (which is the input) hence we observe that base layer frame have lower average quality than their corresponding QCIF single layer encodings.

We observe that in base layer encodings, the mean frame quality $\bar{Q}^b$ does not change as much with changing quantization scale as would be observed in single layer QCIF encodings. This is because already the source base layer video is of low quality (due to downsampling). We observe that *ParkingLot* sequence has very low base quality as the source video sequence was of low quality.

The coefficient of quality variation $CoQV^b$ increases as the quality of encoding decreases however this increase is very small. The alternate coefficient of quality variation $CoQV'^b$ decreases as the quality of encoding decreases. We observe similar behavior for the GoP level also.

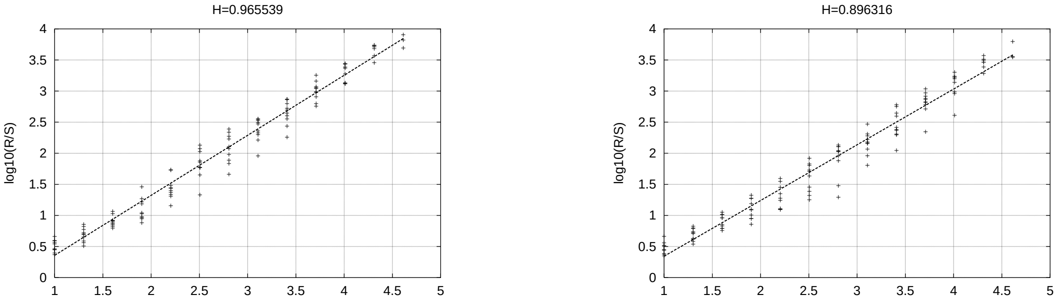
Table 14: Overview of quality statistics of base layer of spatial scalable encoded video

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^b$	$CoQV^b$	$CoQV'^b$	$Q_{\min}^{\max,b}$	$CoQV^{(G),b}$	$CoQV'^{(G),b}$	$Q_{\min}^{\max,(G),b}$
CIF H.Q. No.R.C.	*Silence of the Lambs*	27.858	0.932	0.13	30.117	0.974	0.122	20.967
	Terminator One	24.537	0.883	0.146	34.871	1.032	0.118	26.626
	Snowboard with Comm	22.435	1.058	0.132	32.523	1.085	0.126	21.239
	Oprah w/o Comm	25.337	1.071	0.061	32.036	1.152	0.056	21.437
	LectureHQ-Reisslein	23.489	1.144	0.061	18.319	1.15	0.061	10.571
	ParkingLot	19.465	1.258	0.071	35.128	1.275	0.067	12.088
CIF 040608.Q. No.R.C.	*Silence of the Lambs*	35.104	1.118	0.043	17.387	1.124	0.041	15.492
	Terminator One	24.472	0.885	0.144	34.784	1.033	0.117	26.426
	Snowboard with Comm	22.404	1.061	0.131	32.500	1.088	0.124	21.206
	Oprah w/o Comm	25.205	1.077	0.060	31.815	1.157	0.055	21.167
	LectureHQ-Reisslein	23.464	1.145	0.061	18.249	1.151	0.061	10.505
	ParkingLot	19.464	1.262	0.071	35.619	1.278	0.066	12.038
CIF 060810.Q. No.R.C.	*Silence of the Lambs*	34.222	1.101	0.050	15.838	1.106	0.049	14.481
	Terminator One	24.407	0.887	0.142	34.801	1.035	0.116	26.386
	Snowboard with Comm	22.372	1.062	0.130	32.435	1.090	0.123	21.172
	Oprah w/o Comm	25.111	1.080	0.060	31.675	1.160	0.055	21.087
	LectureHQ-Reisslein	23.426	1.146	0.061	18.177	1.152	0.061	10.478
	ParkingLot	19.450	1.265	0.070	35.627	1.282	0.066	11.998
CIF H.M.Q. No.R.C.	*Silence of the Lambs*	27.507	0.944	0.125	29.793	0.985	0.117	20.442
	Terminator One	24.33	0.89	0.14	34.221	1.037	0.114	26.074
	Snowboard with Comm	22.331	1.064	0.129	31.978	1.091	0.123	21.170
	Oprah w/o Comm	25.023	1.084	0.06	31.717	1.163	0.055	20.797
	LectureHQ-Reisslein	23.335	1.148	0.061	18.137	1.154	0.06	10.447
	ParkingLot	19.414	1.268	0.069	33.849	1.285	0.065	11.962

Table 14: *continued*

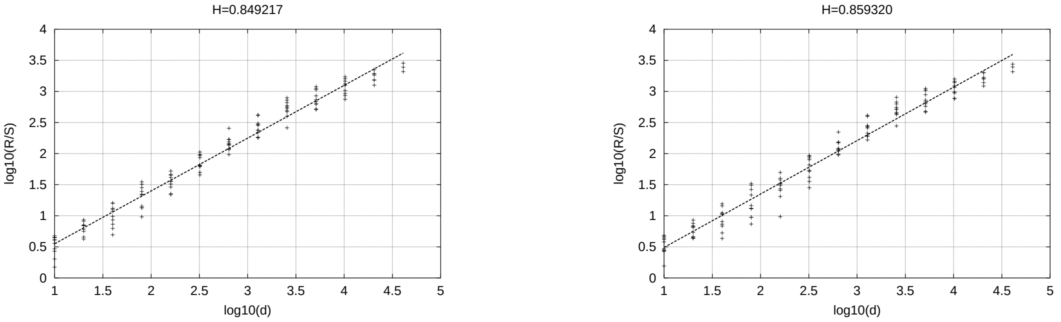
CIF M.Q. No.R.C.	*Silence of the Lambs*	27.386	0.947	0.125	29.698	0.987	0.118	20.405
	Terminator One	24.193	0.895	0.138	34.23	1.04	0.114	26.050
	Snowboard with Comm	22.243	1.068	0.128	31.949	1.095	0.121	21.167
	Oprah w/o Comm	24.82	1.092	0.059	31.705	1.169	0.055	20.792
	LectureHQ-Reisslein	23.3	1.15	0.061	18.095	1.156	0.06	10.460
	ParkingLot	19.385	1.274	0.067	34.513	1.291	0.064	11.873
CIF M.L.Q. No.R.C.	*Silence of the Lambs*	26.678	0.968	0.12	28.562	1.003	0.114	19.423
	Terminator One	23.68	0.914	0.132	32.627	1.056	0.112	25.079
	Snowboard with Comm	21.87	1.083	0.125	30.719	1.109	0.119	20.632
	Oprah w/o Comm	24.129	1.118	0.059	31.552	1.189	0.055	20.808
	LectureHQ-Reisslein	22.811	1.158	0.061	17.751	1.163	0.061	10.351
	ParkingLot	19.105	1.301	0.064	32.26	1.317	0.061	11.618
CIF L.Q. No.R.C.	*Silence of the Lambs*	26.384	0.975	0.119	27.7	1.007	0.114	19.034
	Terminator One	23.404	0.924	0.13	32.581	1.065	0.111	24.614
	Snowboard with Comm	21.658	1.09	0.125	30.548	1.115	0.119	20.696
	Oprah w/o Comm	23.789	1.13	0.059	31.228	1.197	0.055	20.546
	LectureHQ-Reisslein	22.57	1.162	0.062	17.376	1.166	0.061	10.143
	ParkingLot	18.94	1.313	0.063	33.35	1.329	0.06	11.427
CIF 64 kbps R.C.	*Silence of the Lambs*	26.659	0.961	0.136	29.496	0.991	0.131	20.740
	Terminator One	23.361	0.925	0.131	33.753	1.066	0.113	26.335
	Snowboard with Comm	21.617	1.091	0.125	30.022	1.115	0.119	20.373
	Oprah w/o Comm	23.742	1.132	0.059	31.193	1.199	0.055	20.499
	LectureHQ-Reisslein	22.889	1.136	0.066	17.307	1.14	0.066	10.060
	ParkingLot	18.902	1.315	0.063	29.947	1.331	0.06	11.440
CIF 128 kbps R.C.	*Silence of the Lambs*	27.36	0.939	0.135	29.992	0.97	0.129	21.418
	Terminator One	23.875	0.904	0.145	34.864	1.039	0.126	26.598
	Snowboard with Comm	21.83	1.078	0.132	32.386	1.102	0.126	21.064
	Oprah w/o Comm	24.499	1.097	0.063	31.886	1.162	0.059	21.179
	LectureHQ-Reisslein	23.274	1.142	0.063	18.279	1.147	0.062	10.874
	ParkingLot	18.959	1.309	0.064	34.233	1.325	0.06	11.440
CIF 256 kbps R.C.	*Silence of the Lambs*	27.641	0.935	0.132	29.98	0.971	0.124	21.385
	Terminator One	24.283	0.891	0.146	34.687	1.033	0.122	26.438
	Snowboard with Comm	22.206	1.066	0.132	32.212	1.091	0.126	21.070
	Oprah w/o Comm	24.897	1.085	0.062	31.958	1.157	0.058	21.329
	LectureHQ-Reisslein	23.397	1.144	0.062	18.312	1.149	0.061	10.665
	ParkingLot	19.31	1.279	0.068	34.912	1.294	0.064	11.952

Figure 24 gives the video frame qualities Q_n^b (in dB) as a function of the frame number n. Its quite interesting to observe that encodings with and without rate control for a given video sequence shows a very similar quality variation pattern in the plot. However looking at the values we notice that there is a small difference between different quality encodings.



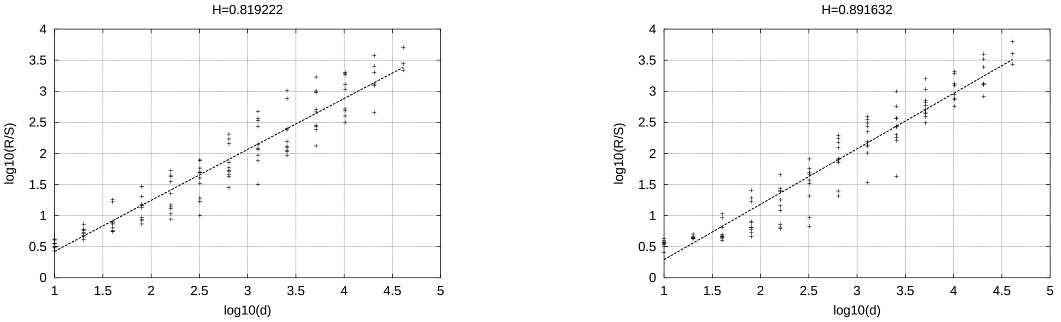
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



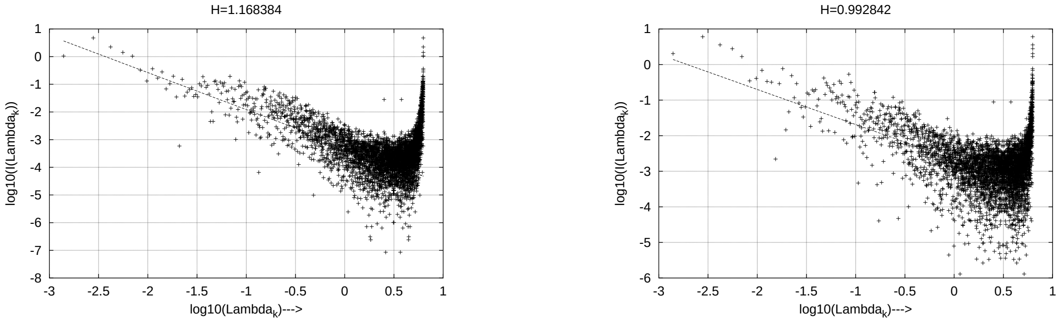
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

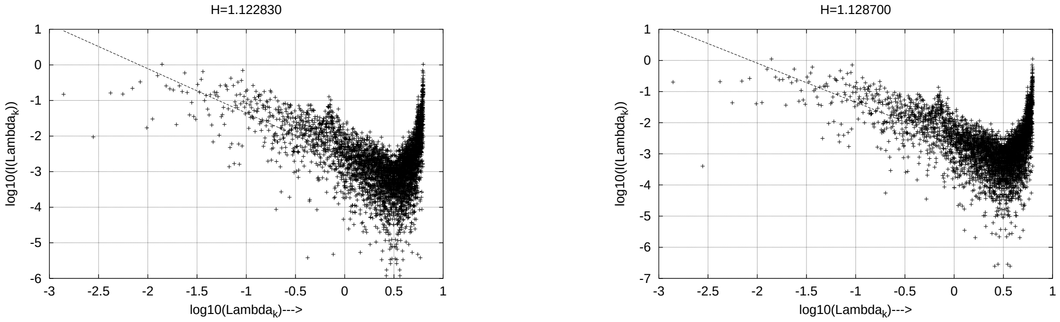
Encoding without rate control

Encoding with rate control

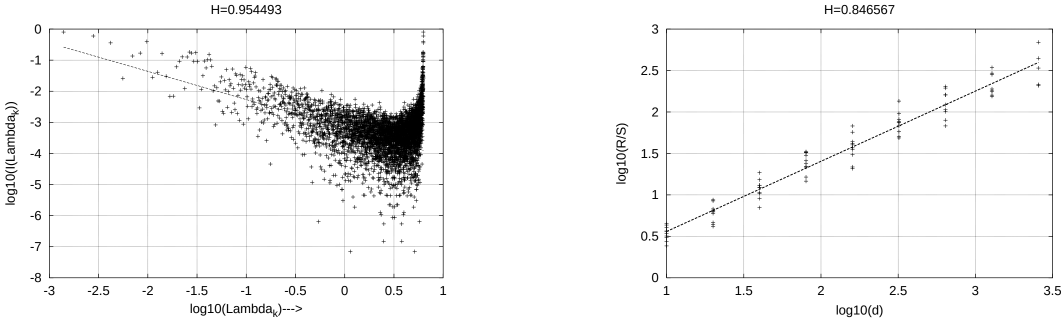
Figure 19: Pox plots of R/S for aggregation level $a = 12$ for enhancement layer of spatial scalable CIF video.



a) *Silence of the Lambs* with high quality d) *Silence of the Lambs* with 256 kbps target bit rate



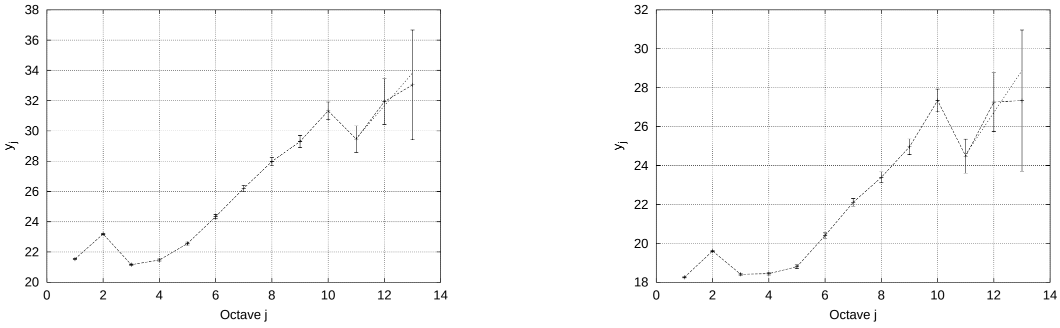
b) *Snowboard with Comm* with medium quality e) *Snowboard with Comm* with 128 kbps target bit rate



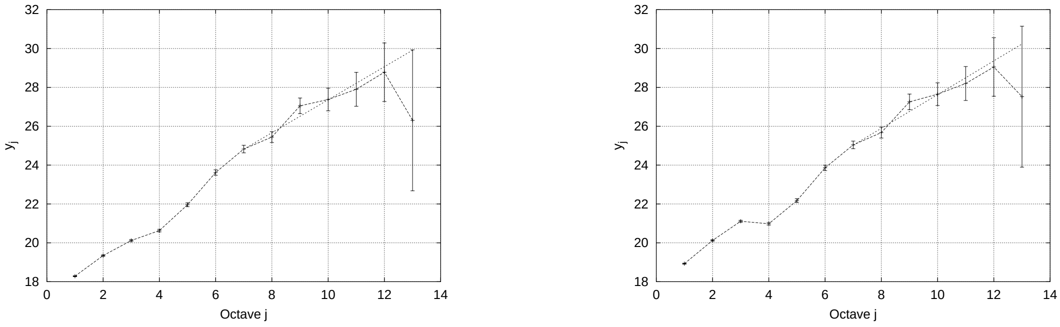
c) *Oprah w/o Comm* with low quality f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control Encoding with rate control

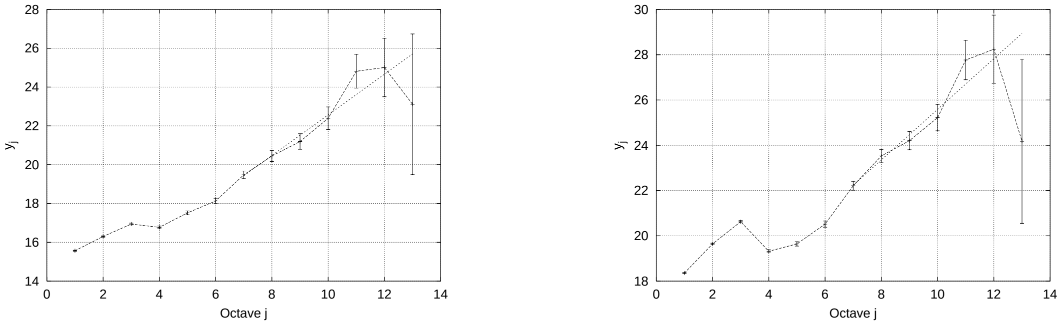
Figure 20: Periodograms for aggregation level $a = 12$ for enhancement layer of spatial scalable CIF video.



a) *Silence of the Lambs* with high quality d) *Silence of the Lambs* with 256 kbps target bit rate



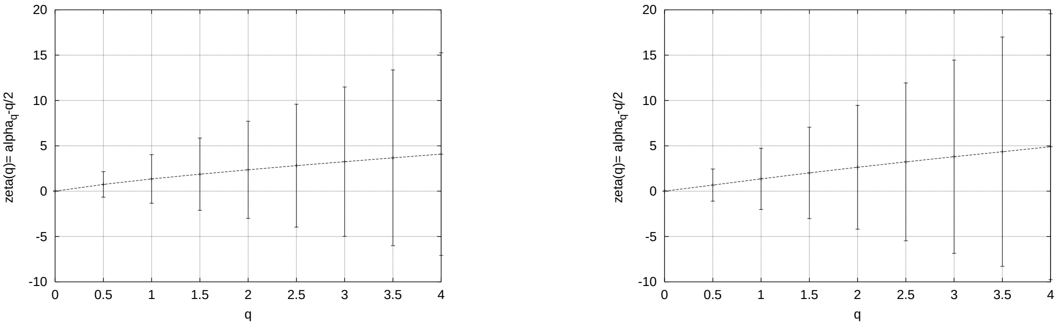
b) *Snowboard with Comm* with medium quality e) *Snowboard with Comm* with 128 kbps target bit rate



c) *Oprah w/o Comm* with low quality f) *Oprah w/o Comm* with 64 kbps target bit rate

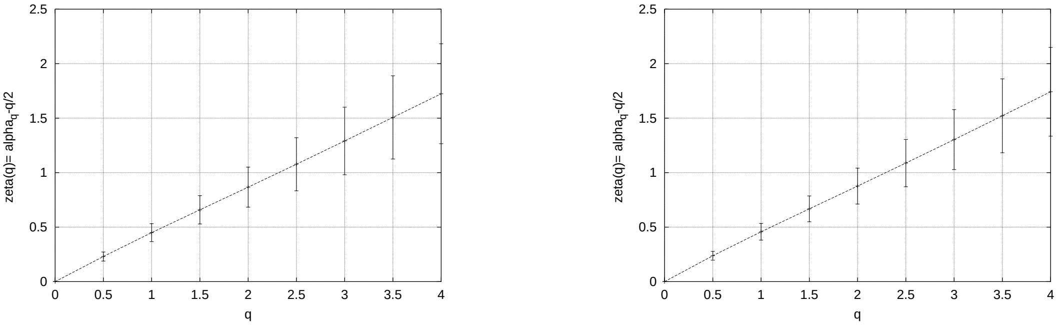
Encoding without rate control Encoding with rate control

Figure 21: Logscale diagrams for enhancement layer of spatial scalable CIF video.



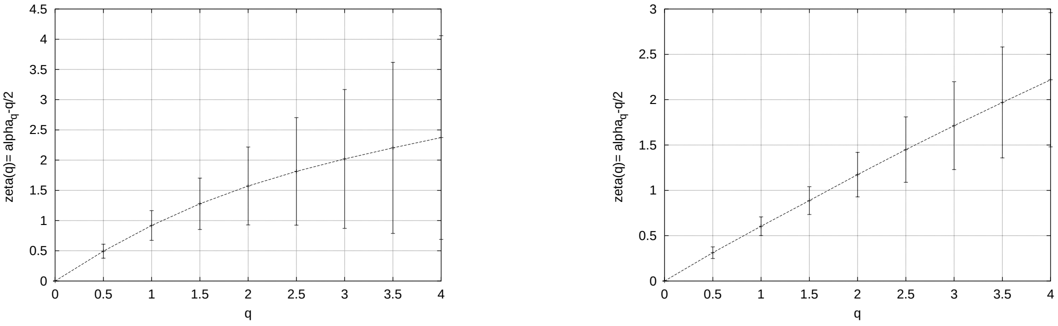
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



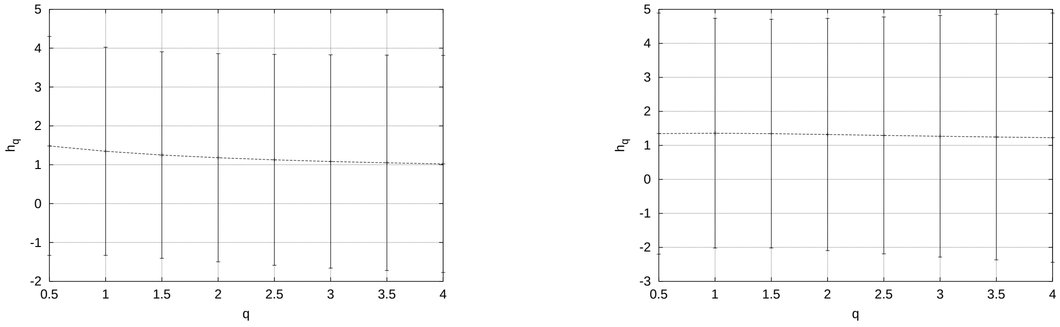
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

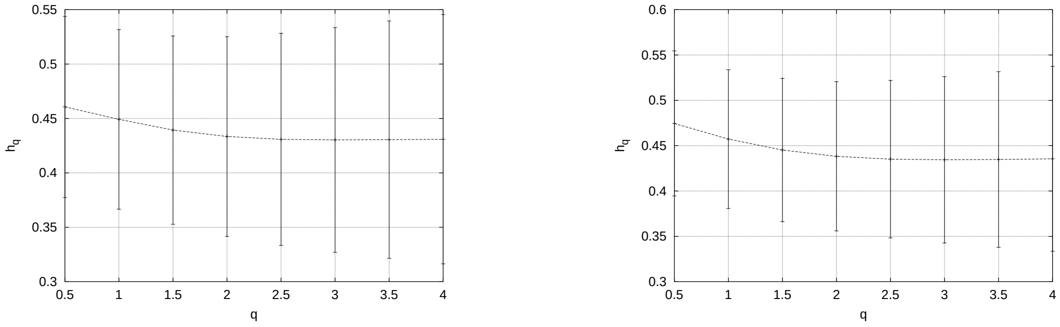
Encoding with rate control

Figure 22: Multiscale diagrams for enhancement layer of spatial scalable CIF video.



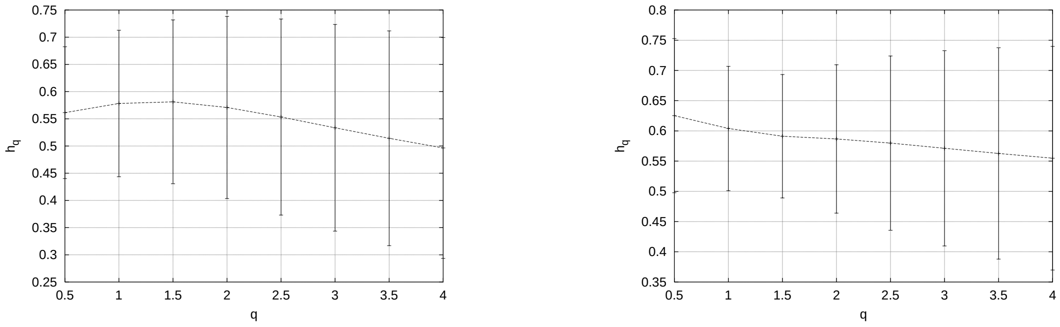
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



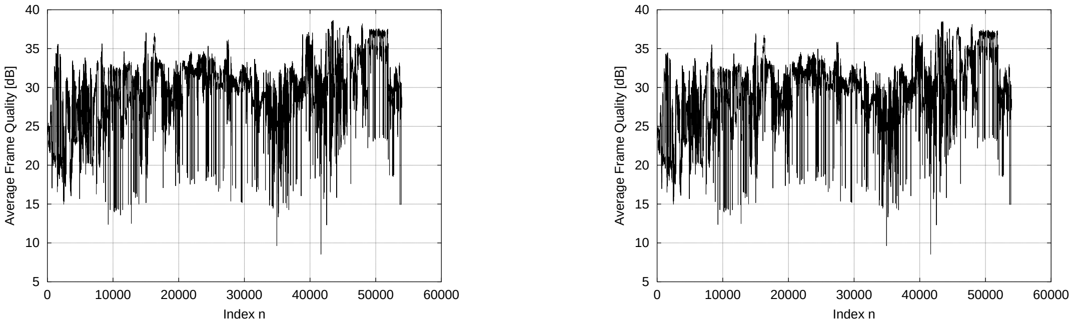
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

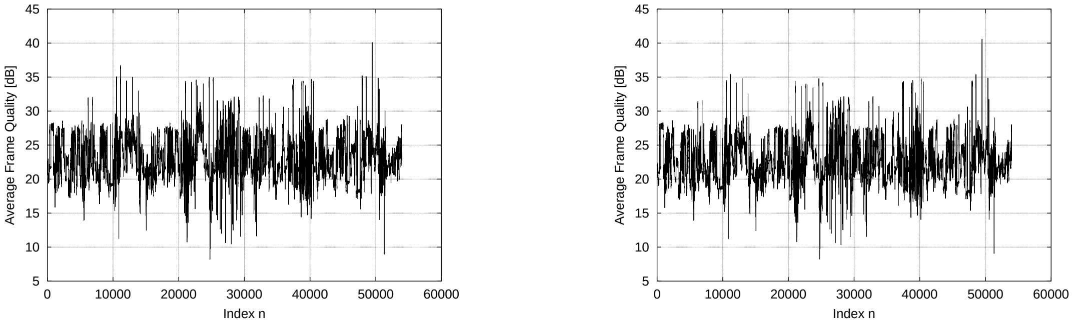
Encoding with rate control

Figure 23: Linear multiscale diagrams for enhancement layer of spatial scalable CIF video.



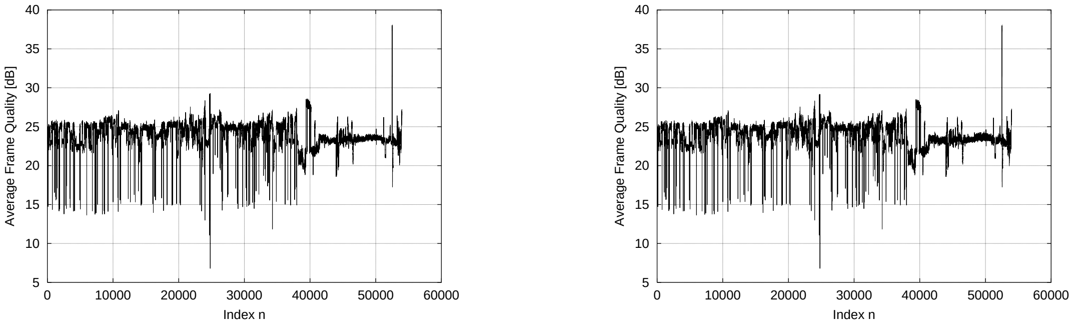
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

Encoding with rate control

Figure 24: Video frame quality Q_n^b (in dB) as a function of the frame index n for the base layer of spatial scalable CIF video.

Figure 25 gives the histogram of the frame qualities Q_n^b. For different quality encodings of the same video sequence we notice that the quality distribution function look alike with some minor differences. This is unlike QCIF single layer encoding frame quality distribution plots given in Part2 of the technical report series. This fact is also corroborated by the fact that coefficient of variation (base layer quality) and mean frame quality changes very little with changing quality of encodings.

Figure 26 gives the MSE autocorrelation coefficient $\rho_M(k)$ as a function of lag k (in frames). For high quality encodings we observe a chain of spikes superimposed on a decreasing slope curve. These spikes are due to high quality I frames as compared to P and B frames. These spikes occur periodically at 12 frame period corresponding to the frequency of I frames. As the quality of encoding decreases this difference in quality between I, P, and B frames decreases, hence we find near smooth curve for low quality encodings. As the frame quality behavior is alike for rate control sequences also, we find the autocorrelation functions also to be similar. Figure 27 gives the MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of lag k (in GoPs). These tend to be smoother as the mean square error is averaged over a GoP now.

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 15 gives the average quality $\bar{Q}^{agg}$, the coefficient of quality variation $CoQV^{agg}$, the quality range $Q_{\text{min}}^{\text{max},agg}$ for the decoded base layer stream. The quality statistics are provided for the frame-level and the GoP-level. Table 16 gives the corresponding statistics for single layer encodings.

We observe that spatial scalable encoding gives somewhat lower quality frame (on an average 1 dB) when compared to the corresponding single layer encoding frame quality. This difference is however very small for high quality encodings. In some cases this can be as low as 3 dB (*ParkingLot* and *LectureHQ-Reisslein* at 101010 quality encoding). Average frame quality can degrade upto 7dB when we change the encoding from high quality to low quality.

When comparing the CIF single layer encoding frame size with the aggregated CIF spatially encoded frame size, one has to be careful. In order to have a fair comparison, we need to see that both of them (single and spatial) achieve approximately the same quality. For example *Oprah* *w/o Commercials* gives an average quality of 36.10 dB (at H.Q. corresponding to 040404)), which is closest to single layer 040404 quality encoding which gives 36.24 dB. When we consider the mean frame size, then we see that spatial encoding has 22.42 KB whereas single layer has 19.27 KB (which corresponds to 16.33 percent overhead in framesize).

The coefficient of quality variation decreases with decreasing quality of encoding, whereas the alternative coefficient of quality variation increases with decreasing quality of encoding. For GoP aggregation level, we find that $CoQV^{(G),agg}$ and $CoQV'^{(G),agg}$ are roughly same as was obtained for frame level.

Table 15: Overview of quality statistics of aggregated layer of spatial scalable encoded video

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}^{agg}$	$CoQV^{agg}$	$CoQV'^{agg}$	$Q_{\mathrm{min}}^{\mathrm{max},agg}$	$CoQV^{(G),agg}$	$CoQV'^{(G),agg}$	$Q_{\mathrm{min}}^{\mathrm{max},(G),agg}$
CIF	*Silence of the Lambs*	37.746	1.21	0.02	13.958	1.212	0.02	13.438
H.Q.	*Terminator One*	37.846	1.198	0.025	14.339	1.203	0.023	13.576
No.R.C.	*Snowboard with Comm*	36.889	1.223	0.025	12.755	1.227	0.023	9.373
	Oprah w/o Comm	36.104	1.272	0.014	4.433	1.272	0.014	4.166
	LectureHQ-Reisslein	30.679	0.913	0.15	23.836	0.913	0.15	18.093
	ParkingLot	36.811	1.307	0.01	11.559	1.312	0.009	4.812
CIF	*Silence of the Lambs*	35.104	1.118	0.043	17.387	1.124	0.041	15.492
040608.Q.	*Terminator One*	34.487	1.137	0.047	17.885	1.149	0.042	14.924
No.R.C.	*Snowboard with Comm*	33.033	1.168	0.042	15.486	1.181	0.037	10.355
	Oprah w/o Comm	31.806	1.211	0.033	9.232	1.227	0.030	8.511
	LectureHQ-Reisslein	34.655	1.199	0.025	6.770	1.209	0.022	5.339
	ParkingLot	32.316	1.246	0.024	15.469	1.284	0.017	5.803
CIF	*Silence of the Lambs*	34.222	1.101	0.050	15.838	1.106	0.049	14.481
060810.Q.	*Terminator One*	33.378	1.128	0.052	15.792	1.140	0.048	13.846
No.R.C.	*Snowboard with Comm*	31.901	1.157	0.048	16.168	1.165	0.045	10.456
	Oprah w/o Comm	30.735	1.222	0.033	10.365	1.230	0.032	9.811
	LectureHQ-Reisslein	31.892	1.081	0.065	11.718	1.081	0.065	8.787
	ParkingLot	28.888	1.059	0.080	21.684	1.060	0.079	11.272
CIF	*Silence of the Lambs*	33.99	1.105	0.05	15.522	1.108	0.049	14.485
H.M.Q.	*Terminator One*	33.189	1.132	0.052	15.567	1.141	0.049	13.820
No.R.C.	*Snowboard with Comm*	31.751	1.161	0.047	15.935	1.165	0.045	10.164
	Oprah w/o Comm	30.598	1.239	0.03	10.285	1.241	0.03	9.722
	LectureHQ-Reisslein	32.982	1.192	0.028	6.699	1.195	0.028	6.202
	ParkingLot	30.553	1.278	0.022	15.762	1.284	0.021	5.683
CIF	*Silence of the Lambs*	32.398	1.072	0.066	17.318	1.076	0.064	15.962
M.Q.	*Terminator One*	31.133	1.114	0.067	17.476	1.126	0.062	14.933
No.R.C.	*Snowboard with Comm*	29.617	1.138	0.063	18.352	1.143	0.061	11.301
	Oprah w/o Comm	28.915	1.239	0.033	12.871	1.242	0.032	12.152
	LectureHQ-Reisslein	30.761	1.184	0.035	8.379	1.185	0.035	7.638
	ParkingLot	27.84	1.268	0.031	20.219	1.273	0.03	6.480
CIF	*Silence of the Lambs*	30.571	1.058	0.078	17.838	1.063	0.076	15.959
M.L.Q.	*Terminator One*	29.07	1.11	0.078	16.598	1.124	0.073	14.568
No.R.C.	*Snowboard with Comm*	27.52	1.131	0.077	18.382	1.136	0.074	12.165
	Oprah w/o Comm	27.351	1.241	0.035	14.715	1.248	0.034	13.837
	LectureHQ-Reisslein	28.204	1.178	0.044	9.336	1.18	0.043	8.684
	ParkingLot	25.216	1.28	0.04	20.574	1.288	0.038	7.055
CIF	*Silence of the Lambs*	29.744	1.05	0.084	18.48	1.055	0.081	16.141
L.Q.	*Terminator One*	28.092	1.107	0.084	17.33	1.122	0.079	14.661
No.R.C.	*Snowboard with Comm*	26.493	1.128	0.084	17.809	1.134	0.081	12.730
	Oprah w/o Comm	26.594	1.235	0.038	15.732	1.243	0.037	14.647
	LectureHQ-Reisslein	27.065	1.176	0.047	9.863	1.179	0.046	9.012
	ParkingLot	24.007	1.286	0.045	23.812	1.294	0.043	7.412
CIF	*Silence of the Lambs*	32.299	1.071	0.068	17.797	1.075	0.067	16.483
64 kbps	*Terminator One*	30.967	1.118	0.066	17.307	1.13	0.061	15.741
R.C.	*Snowboard with Comm*	29.51	1.141	0.062	17.986	1.146	0.06	11.532
	Oprah w/o Comm	28.817	1.247	0.031	12.578	1.25	0.031	11.795
	LectureHQ-Reisslein	30.629	1.181	0.036	8.217	1.182	0.036	7.444
	ParkingLot	27.752	1.273	0.031	19.034	1.278	0.029	6.421
CIF	*Silence of the Lambs*	32.645	1.057	0.072	18.638	1.061	0.07	16.975
128 kbps	*Terminator One*	31.097	1.109	0.071	18.577	1.121	0.066	15.743
R.C.	*Snowboard with Comm*	29.552	1.137	0.064	19.03	1.142	0.062	11.530
	Oprah w/o Comm	28.86	1.238	0.034	13.384	1.241	0.033	12.599
	LectureHQ-Reisslein	30.817	1.173	0.037	8.582	1.174	0.037	7.901
	ParkingLot	27.762	1.271	0.031	20.43	1.276	0.03	6.472
CIF	*Silence of the Lambs*	32.988	1.049	0.072	18.625	1.054	0.07	16.890
256 kbps	*Terminator One*	31.353	1.1	0.073	18.873	1.113	0.068	16.339
R.C.	*Snowboard with Comm*	29.666	1.132	0.066	19.017	1.137	0.063	11.669
	Oprah w/o Comm	28.984	1.226	0.036	13.351	1.229	0.036	12.791
	LectureHQ-Reisslein	31.024	1.173	0.037	8.742	1.174	0.037	8.052
	ParkingLot	27.868	1.261	0.033	20.799	1.265	0.031	6.512

Table 16: Overview of quality statistics of single-layer traces

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}$ dB	$CoQV$	$CoQV'$	$Q_{\min}^{\max}$ dB	$CoQV^{(G)}$	$CoQV'^{(G)}$	$Q_{\min}^{\max(G)}$
QCIF	*Citizen Kane*	37.638	0.491	0.030	31.760	0.267	0.026	17.079
H.Q.	*Die Hard I*	36.495	13.646	0.021	49.411	3.934	0.015	36.086
No R.C.	*Jurassic Park I*	36.561	0.197	0.026	14.436	0.158	0.020	6.003
	Silence of the Lambs	37.104	0.186	0.023	18.686	0.160	0.020	12.591
	Star Wars IV	37.073	0.221	0.034	22.776	0.194	0.030	12.008
	Star Wars V	35.986	17.011	0.051	50.579	4.949	0.048	38.759
	The Firm	36.717	0.162	0.020	17.326	0.121	0.014	7.939
	Terminator I	37.045	0.670	0.030	33.085	0.295	0.024	23.851
	Total Recall	36.643	0.182	0.020	27.913	0.116	0.014	13.321
	Aladdin	36.026	0.163	0.024	13.532	0.109	0.016	8.071
	Cinderella	36.154	12.563	0.021	40.847	3.634	0.014	29.675
	Baseball with Comm	35.990	0.204	0.025	42.467	0.123	0.018	12.091
	Snowboard with Comm	36.302	0.521	0.029	34.272	0.239	0.021	21.041
	Oprah w/o Comm	35.688	0.164	0.023	13.260	0.111	0.015	4.424
	Tonight Show w/o Comm	37.674	0.594	0.130	22.366	0.574	0.129	12.518
	Lecture-Gupta	36.215	0.164	0.023	8.609	0.105	0.014	5.865
	Lecture-Reisslein	35.994	0.700	0.046	33.754	0.354	0.042	25.634
QCIF	*Jurassic Park I*	30.782	0.353	0.054	18.984	0.336	0.052	12.470
M.–L.Q	*Star Wars IV*	32.453	0.907	0.050	35.839	0.401	0.048	22.482
No R.C.	*The Firm*	31.752	0.362	0.047	16.458	0.346	0.045	10.802
	Tonight Show w/o Comm	31.831	0.616	0.165	19.217	0.608	0.165	15.940
QCIF	*Citizen Kane*	31.050	0.651	0.067	34.129	0.462	0.062	21.777
M.Q.	*Die Hard I*	30.786	3.685	0.051	43.268	1.104	0.043	29.799
No R.C.	*Jurassic Park I*	29.458	0.465	0.069	22.130	0.419	0.063	15.633
	Silence of the Lambs	31.888	0.577	0.064	24.458	0.543	0.061	16.900
	Star Wars IV	31.378	1.251	0.060	38.338	0.518	0.054	23.540
	Star Wars V	29.980	0.495	0.084	29.725	0.436	0.079	18.598
	The Firm	30.659	0.490	0.061	17.297	0.450	0.057	12.730
	Terminator I	30.201	0.973	0.068	38.452	0.471	0.059	25.788
	Total Recall	30.628	0.523	0.055	30.171	0.360	0.047	16.189
	Aladdin	28.887	0.542	0.058	31.839	0.335	0.048	15.913
	Cinderella	29.825	2.939	0.053	40.574	0.902	0.044	28.950
	Baseball with Comm	29.650	0.472	0.060	53.192	0.340	0.053	18.248
	Snowboard with Comm	28.986	0.483	0.074	28.438	0.412	0.065	15.010
	Oprah w/o Comm	28.471	0.326	0.053	23.833	0.282	0.045	12.626
	Tonight Show w/o Comm	30.678	0.688	0.185	21.046	0.654	0.184	18.843
	Lecture-Gupta	28.360	0.321	0.055	18.180	0.257	0.041	14.984
	Lecture-Reisslein	27.990	0.505	0.133	29.405	0.453	0.129	21.894
QCIF	*Jurassic Park I*	26.535	0.438	0.076	22.388	0.427	0.074	17.069
H.–M.Q.	*Star Wars IV*	28.745	1.097	0.071	36.704	0.537	0.069	23.464
No R.C.	*The Firm*	27.745	1.099	0.076	18.258	1.102	0.075	14.349
	Tonight Show w/o Comm	27.131	0.662	0.231	23.248	0.657	0.231	21.299
QCIF	*Citizen Kane*	26.910	0.532	0.082	33.394	0.472	0.081	22.828
L.Q.	*Die Hard I*	27.132	1.618	0.062	38.709	0.577	0.059	26.407
No R.C.	*Jurassic Park I*	25.681	0.447	0.080	22.461	0.439	0.078	17.653
	Silence of the Lambs	28.446	0.679	0.083	21.224	0.666	0.082	18.621
	Star Wars IV	27.892	1.006	0.075	34.876	0.546	0.073	23.119
	Star Wars V	26.604	0.549	0.103	25.701	0.532	0.101	17.965
	The Firm	26.901	0.559	0.083	22.208	0.548	0.081	15.371
	Terminator I	26.457	0.746	0.084	36.370	0.493	0.080	26.615
	Total Recall	27.029	0.434	0.066	25.233	0.388	0.064	15.572
	Aladdin	25.335	0.471	0.077	27.398	0.412	0.074	14.735
	Cinderella	26.094	1.303	0.065	39.998	0.519	0.063	28.318
	Baseball with Comm	26.303	0.444	0.078	37.139	0.398	0.074	18.972
	Snowboard with Comm	25.177	0.499	0.093	29.342	0.479	0.090	16.379
	Oprah w/o Comm	25.248	0.305	0.053	26.889	0.295	0.051	16.180
	Tonight Show w/o Comm	26.214	0.680	0.256	24.988	0.675	0.256	23.386
	Lecture-Gupta	23.846	0.314	0.065	22.052	0.307	0.064	20.034
	Lecture-Reisslein	24.057	0.523	0.160	28.123	0.517	0.159	21.948
QCIF	*Citizen Kane*	27.383	0.685	0.111	41.183	1.038	0.086	21.405

Table 16: *continued*

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}$ dB	$CoQV$	$CoQV'$	$Q_{\min}^{\max}$ dB	$CoQV^{(G)}$	$CoQV'^{(G)}$	$Q_{\min}^{\max(G)}$
R.C. 64 kbps	*Die Hard I*	27.025	1.585	0.064	39.369	1.498	0.060	37.237
	Jurassic Park I	25.585	0.451	0.085	25.516	0.915	0.092	21.269
	Silence of the Lambs	28.926	0.830	0.108	29.721	1.297	0.074	31.059
	Star Wars IV	27.935	1.053	0.081	48.171	0.868	0.073	28.030
	Star Wars V	26.512	0.557	0.105	43.121	0.773	0.108	32.013
	The Firm	27.041	0.627	0.099	22.591	0.905	0.077	18.442
	Terminator I	26.355	0.770	0.085	44.135	0.813	0.092	28.454
	Total Recall	26.957	0.446	0.071	36.817	0.656	0.067	17.391
	Aladdin	25.221	0.478	0.078	39.523	0.718	0.084	18.341
	Cinderella	25.981	1.270	0.066	39.695	1.204	0.076	30.015
	Baseball with Comm	26.221	0.448	0.080	37.664	0.594	0.071	20.933
	Snowboard with Comm	25.052	0.498	0.094	26.402	0.745	0.104	23.764
	Oprah w/o Comm	25.145	0.307	0.054	32.042	0.548	0.073	17.812
	Tonight Show w/o Comm	26.539	0.741	0.309	31.522	1.000	0.239	29.026
	Lecture-Gupta	23.693	0.315	0.066	22.177	0.543	0.062	20.274
	Lecture-Reisslein	23.912	0.522	0.158	27.713	0.650	0.155	29.749
QCIF R.C. 128 kbps	*Citizen Kane*	30.773	1.272	0.108	44.167	1.096	0.106	24.928
	Die Hard I	29.823	3.021	0.087	54.425	1.071	0.083	33.983
	Jurassic Park I	28.117	0.792	0.109	24.161	0.777	0.106	21.239
	Silence of the Lambs	31.795	1.330	0.097	33.185	1.311	0.095	29.205
	Star Wars IV	30.978	1.769	0.094	48.617	1.014	0.090	30.358
	Star Wars V	28.801	0.864	0.130	38.917	0.830	0.127	30.477
	The Firm	29.928	0.980	0.101	21.811	0.959	0.099	18.229
	Terminator I	28.380	0.931	0.119	44.868	0.764	0.114	27.924
	Total Recall	29.668	0.766	0.092	36.258	0.686	0.088	17.338
	Aladdin	26.120	0.641	0.105	38.624	0.575	0.101	16.320
	Cinderella	28.075	2.076	0.097	49.343	0.861	0.092	29.716
	Baseball with Comm	28.216	0.664	0.094	53.984	0.591	0.089	20.833
	Snowboard with Comm	26.126	0.668	0.123	41.135	0.640	0.119	20.451
	Oprah w/o Comm	27.082	0.526	0.078	30.006	0.510	0.076	18.064
	Tonight Show w/o Comm	29.173	0.987	0.282	31.345	0.973	0.282	29.179
	Lecture-Gupta	26.450	0.578	0.078	29.221	0.557	0.073	20.866
	Lecture-Reisslein	25.809	0.708	0.183	36.308	0.695	0.182	29.105
QCIF R.C. 256 kbps	*Citizen Kane*	33.458	1.140	0.091	39.732	0.552	0.109	24.207
	Die Hard I	32.361	5.307	0.068	58.075	0.511	0.060	27.032
	Jurassic Park I	30.563	0.939	0.096	23.429	0.378	0.083	20.902
	Silence of the Lambs	33.824	1.398	0.078	36.115	0.791	0.106	18.514
	Star Wars IV	33.338	1.063	0.078	44.470	0.525	0.079	22.974
	Star Wars V	30.995	0.807	0.112	38.956	0.483	0.103	17.925
	The Firm	32.231	0.942	0.082	23.975	0.560	0.097	16.938
	Terminator I	31.157	0.937	0.102	46.188	0.441	0.081	25.758
	Total Recall	32.147	0.722	0.074	40.134	0.339	0.068	15.644
	Aladdin	28.461	0.827	0.093	41.964	0.371	0.075	15.004
	Cinderella	30.472	3.487	0.083	41.801	0.462	0.064	28.030
	Baseball with Comm	30.395	0.639	0.078	51.875	0.350	0.077	19.171
	Snowboard with Comm	28.692	0.788	0.111	38.684	0.432	0.090	15.592
	Oprah w/o Comm	28.850	0.536	0.077	29.715	0.247	0.052	16.399
	Tonight Show w/o Comm	31.703	1.045	0.239	30.929	0.689	0.309	28.903
	Lecture-Gupta	28.479	0.536	0.072	26.107	0.244	0.065	20.087
	Lecture-Reisslein	27.794	0.655	0.157	37.269	0.464	0.158	20.260
CIF 040404. No.R.C.	*Silence of the Lambs*	37.896	1.197	0.023	15.978	1.212	0.02	13.809
	Terminator I	38.009	1.1	0.028	33.403	1.183	0.023	20.934
	Snowboard with Comm	37.025	1.198	0.029	18.211	1.225	0.023	9.590
	Oprah w/o Comm	36.24	1.221	0.022	4.986	1.262	0.015	4.261
	ParkingLot	37.039	1.232	0.020	12.739	1.317	0.009	5.064
	LectureHQ-Reisslein	38.303	1.218	0.017	4.451	1.248	0.012	3.017
CIF 040608. No.R.C.	*Silence of the Lambs*	35.842	1.108	0.046	21.393	1.13	0.036	15.650
	Terminator I	35.213	1.033	0.055	37.597	1.124	0.039	22.261
	Snowboard with Comm	33.752	1.129	0.058	27.126	1.181	0.035	11.886
	Oprah w/o Comm	32.437	1.138	0.063	10.367	1.199	0.035	8.295

Table 16: *continued*

		Frame Level				GoP level		
Enc. M.	Video	$\bar{Q}$ dB	$CoQV$	$CoQV'$	$Q_{\min}^{\max}$ dB	$CoQV^{(G)}$	$CoQV'^{(G)}$	$Q_{\min}^{\max(G)}$
	ParkingLot	33.453	1.152	0.055	18.518	1.246	0.020	6.428
	LectureHQ-Reisslein	36.061	1.166	0.036	9.320	1.221	0.018	4.886
CIF 060810. No.R.C.	*Silence of the Lambs*	35.023	1.094	0.049	17.126	1.106	0.045	14.369
	Terminator I	34.042	0.955	0.056	34.355	1.074	0.045	22.098
	Snowboard with Comm	32.601	1.13	0.054	22.813	1.164	0.042	12.358
	Oprah w/o Comm	31.312	1.162	0.052	10.923	1.197	0.039	9.589
	ParkingLot	31.720	1.173	0.046	19.774	1.213	0.029	6.801
	LectureHQ-Reisslein	34.917	1.178	0.031	9.045	1.210	0.021	5.627
CIF 101010. No.R.C.	*Silence of the Lambs*	34.337	1.1	0.05	15.962	1.105	0.049	14.594
	Terminator I	33.377	0.935	0.054	34.545	1.061	0.049	22.844
	Snowboard with Comm	32.004	1.135	0.049	26.308	1.161	0.045	12.456
	Oprah w/o Comm	30.802	1.215	0.035	10.827	1.223	0.033	9.842
	ParkingLot	30.989	1.243	0.027	17.658	1.269	0.022	6.137
	LectureHQ-Reisslein	33.626	1.189	0.028	7.345	1.197	0.026	5.979
CIF 101416. No.R.C.	*Silence of the Lambs*	33.423	1.06	0.063	19.029	1.069	0.06	16.354
	Terminator I	31.891	0.925	0.069	35.746	1.05	0.06	24.889
	Snowboard with Comm	30.483	1.109	0.065	27.492	1.137	0.057	12.469
	Oprah w/o Comm	29.679	1.183	0.046	13.288	1.202	0.041	11.985
	ParkingLot	29.305	1.163	0.050	25.563	1.196	0.037	7.342
	LectureHQ-Reisslein	32.824	1.176	0.034	10.257	1.195	0.028	7.299
CIF 242424. No.R.C.	*Silence of the Lambs*	31.384	1.044	0.078	19.35	1.05	0.075	17.446
	Terminator I	29.635	0.978	0.08	34.17	1.084	0.073	22.825
	Snowboard with Comm	28.128	1.115	0.077	27.72	1.128	0.074	12.406
	Oprah w/o Comm	27.907	1.226	0.037	14.79	1.233	0.035	13.661
	ParkingLot	25.975	1.248	0.041	24.081	1.259	0.039	7.921
	LectureHQ-Reisslein	29.358	1.175	0.041	10.349	1.177	0.041	8.588
CIF 303030. No.R.C.	*Silence of the Lambs*	30.677	1.034	0.083	21.594	1.04	0.081	19.161
	Terminator I	28.772	1.002	0.085	33.798	1.092	0.078	22.608
	Snowboard with Comm	27.214	1.114	0.084	25.721	1.125	0.08	13.130
	Oprah w/o Comm	27.254	1.224	0.039	15.139	1.232	0.037	14.234
	ParkingLot	24.849	1.255	0.046	26.193	1.264	0.043	8.416
	LectureHQ-Reisslein	28.315	1.175	0.044	10.779	1.177	0.044	8.966
CIF R.C. 64kbps	*Silence of the Lambs*	30.591	1.033	0.084	21.553	1.039	0.081	19.117
	Terminator I	28.665	1.002	0.086	33.675	1.093	0.079	22.660
	Snowboard with Comm	27.096	1.114	0.085	26.082	1.125	0.081	13.058
	Oprah w/o Comm	27.17	1.224	0.039	15.39	1.232	0.037	14.380
	ParkingLot	24.708	1.257	0.046	23.604	1.266	0.044	8.422
	LectureHQ-Reisslein	28.170	1.175	0.045	10.756	1.177	0.044	8.843
CIF R.C. 128kbps	*Silence of the Lambs*	30.595	1.033	0.084	21.553	1.039	0.081	19.117
	Terminator I	28.665	1.002	0.086	33.675	1.093	0.079	22.660
	Snowboard with Comm	27.096	1.114	0.085	26.082	1.125	0.081	13.058
	Oprah w/o Comm	27.17	1.224	0.039	15.39	1.232	0.037	14.380
	ParkingLot	24.708	1.257	0.046	23.604	1.266	0.044	8.422
	LectureHQ-Reisslein	28.170	1.175	0.045	10.744	1.177	0.044	8.738
CIF R.C. 256kbps	*Silence of the Lambs*	31.095	1.011	0.102	28.151	1.017	0.099	19.117
	Terminator I	28.671	1.001	0.087	33.675	1.092	0.08	22.660
	Snowboard with Comm	27.105	1.113	0.085	26.082	1.124	0.081	13.058
	Oprah w/o Comm	27.295	1.203	0.046	16.322	1.209	0.044	14.884
	ParkingLot	24.711	1.256	0.046	23.604	1.265	0.044	8.917
	LectureHQ-Reisslein	31.626	1.082	0.057	16.819	1.086	0.055	12.107
CIF R.C. 512kbps	*ParkingLot*	25.916	1.109	0.103	31.281	1.116	0.097	11.652
	LectureHQ-Reisslein	33.879	1.096	0.045	16.467	1.105	0.042	12.460
CIF R.C. 1024kbps	*ParkingLot*	28.797	1.040	0.096	30.631	1.054	0.089	13.807
	LectureHQ-Reisslein	35.772	1.113	0.037	17.747	1.130	0.033	11.243

Figure 28 gives the video frame qualities Q_n^{agg} (in dB) as a function of the frame number n.

Unlike the base layer plots, these plots show a difference in quality variation for rate controlled and non rate controlled encodings. This is because rate control is only applied to the base layer, whereas the enhancement layer is fixed at medium quality. In encodings without rate control both base and enhancement layer have the same quality parameters. However, when we compare the same video sequence without rate control at different quality levels, we find that the quality variation plots are similar.

Figure 29 gives the histogram of the frame qualities Q_n^{agg}. In most of the high quality encoding without rate control plots we observe double peaks (usually a small peak at very high quality). This is because of the high quality I frames which constitute around 8.3 percent of total frames. This small peak vanishes as the quality of encoding decreases (because of the decreasing gap between between I frame quality and the P and B frame quality).

Figure 30 gives the MSE autocorrelation coefficient $\rho_M(k)$ as a function of lag k (in frames) and Figure 27 gives the MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of lag k (in GoPs). We find similar observations as was reported in Figure 26 and Figure 27.

4 Correlation between Frame Sizes and Qualities

Table 17 gives the correlation coefficients between 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, both for the frame level and the GoP aggregation level.

We notice that correlation coefficients ρ_{XQ} for base layer traffic is negative for all encodings including rate control. For the aggregated stream we find that ρ_{XQ} is negative in most cases except for *LectureHQ-Reisslein* and *ParkingLot* sequences encoded at the high, 040608, and 060810 quality levels. We find these values are more negative at the H.M quality level compared to other encodings and quality levels for aggregated stream traffic. When compared to the base layer traffic correlation coefficients, we find these values are a little bit more negative for the aggregated traffic in most cases, this is because of the fact that when we take into consideration the aggregated stream which is formed by adding enhancement layer (CIF which is nearly 3 times larger) to the base layer (QCIF). This aggregated stream however increases by nearly a factor of 4 but its quality does not change that much. Hence we find that (X,Q) plots tends to show a more negative slope and hence more negative correlation coefficients. When compared to single layer CIF encodings, we find that ρ_{XQ} is positive for all of the sequences encoded at 040608 quality level and the values tend to be lesser negative than there spatial counterparts for other encodings.

Table 17: Correlation between quality and traffic for spatial 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}	$\rho_{XM}^{(G)}$	$\rho_{XQ}^{(G)}$
CIF	*Silence of the Lambs*	0.527	-0.617	0.877	-0.857	0.747	-0.652	0.807	-0.706
H.Q.	*Terminator One*	0.191	-0.466	0.624	-0.841	0.69	-0.591	0.811	-0.714
No.R.C.	*Snowboard with Comm*	0.499	-0.545	0.666	-0.678	0.491	-0.423	0.536	-0.456
	Oprah w/o Comm	0.164	-0.227	0.312	-0.309	0.788	-0.773	0.851	-0.835
	LectureHQ-Reisslein	0.218	-0.222	0.655	-0.648	-0.007	0.01	-0.016	0.012
	ParkingLot	0.265	-0.227	0.36	-0.306	-0.078	0.049	0.013	-0.022
CIF	*Silence of the Lambs*	0.246	-0.208	0.864	-0.783	0.576	-0.510	0.846	-0.763
040608.Q.	*Terminator One*	0.113	-0.262	0.652	-0.856	0.466	-0.430	0.811	-0.763
No.R.C.	*Snowboard with Comm*	0.295	-0.313	0.680	-0.684	0.312	-0.286	0.765	-0.709
	Oprah w/o Comm	0.092	-0.125	0.444	-0.440	0.138	-0.120	0.849	-0.819
	LectureHQ-Reisslein	0.094	-0.095	0.602	-0.591	-0.169	0.214	0.720	-0.705
	ParkingLot	0.168	-0.141	0.352	-0.297	-0.114	0.177	0.621	-0.565
CIF	*Silence of the Lambs*	0.351	-0.314	0.854	-0.764	0.647	-0.575	0.837	-0.747
060810.Q.	*Terminator One*	0.123	-0.272	0.668	-0.863	0.540	-0.502	0.778	-0.737
No.R.C.	*Snowboard with Comm*	0.317	-0.333	0.680	-0.681	0.449	-0.429	0.772	-0.723
	Oprah w/o Comm	0.108	-0.147	0.523	-0.516	0.292	-0.278	0.840	-0.795
	LectureHQ-Reisslein	0.093	-0.094	0.584	-0.573	-0.152	0.155	-0.352	0.274
	ParkingLot	0.174	-0.145	0.351	-0.296	-0.212	0.226	-0.263	0.230
CIF	*Silence of the Lambs*	0.473	-0.497	0.875	-0.787	0.754	-0.666	0.817	-0.726
H.M.Q.	*Terminator One*	0.174	-0.374	0.674	-0.863	0.673	-0.614	0.757	-0.717
No.R.C.	*Snowboard with Comm*	0.436	-0.461	0.684	-0.685	0.684	-0.638	0.759	-0.712
	Oprah w/o Comm	0.189	-0.261	0.558	-0.546	0.703	-0.66	0.825	-0.773
	LectureHQ-Reisslein	0.124	-0.126	0.544	-0.53	0.339	-0.327	0.632	-0.617
	ParkingLot	0.217	-0.182	0.337	-0.283	0.474	-0.422	0.482	-0.428
CIF	*Silence of the Lambs*	0.324	-0.33	0.862	-0.77	0.666	-0.57	0.802	-0.694
M.Q.	*Terminator One*	0.114	-0.229	0.698	-0.866	0.559	-0.504	0.69	-0.654
No.R.C.	*Snowboard with Comm*	0.274	-0.281	0.679	-0.669	0.521	-0.492	0.735	-0.687
	Oprah w/o Comm	0.086	-0.106	0.613	-0.59	0.422	-0.395	0.814	-0.758
	LectureHQ-Reisslein	0.082	-0.083	0.644	-0.631	0.117	-0.113	0.577	-0.561
	ParkingLot	0.155	-0.131	0.374	-0.322	0.337	-0.291	0.609	-0.529
CIF	*Silence of the Lambs*	0.384	-0.374	0.778	-0.678	0.674	-0.565	0.732	-0.626
M.L.Q.	*Terminator One*	0.159	-0.276	0.679	-0.778	0.56	-0.491	0.574	-0.553
No.R.C.	*Snowboard with Comm*	0.317	-0.31	0.624	-0.597	0.579	-0.531	0.636	-0.599
	Oprah w/o Comm	0.132	-0.156	0.463	-0.401	0.533	-0.486	0.593	-0.546
	LectureHQ-Reisslein	0.083	-0.085	0.495	-0.482	0.273	-0.262	0.453	-0.434
	ParkingLot	0.175	-0.147	0.314	-0.263	0.427	-0.353	0.392	-0.325
CIF	*Silence of the Lambs*	0.356	-0.349	0.713	-0.632	0.64	-0.538	0.69	-0.596
L.Q.	*Terminator One*	0.159	-0.26	0.643	-0.712	0.529	-0.458	0.521	-0.508
No.R.C.	*Snowboard with Comm*	0.283	-0.268	0.559	-0.528	0.534	-0.49	0.574	-0.545
	Oprah w/o Comm	0.129	-0.147	0.398	-0.338	0.445	-0.397	0.442	-0.401
	LectureHQ-Reisslein	0.078	-0.081	0.44	-0.433	0.257	-0.25	0.379	-0.360
	ParkingLot	0.166	-0.138	0.296	-0.243	0.38	-0.305	0.326	-0.263
CIF	*Silence of the Lambs*	0.149	-0.101	0.511	-0.323	0.648	-0.55	0.777	-0.666
64 kbps	*Terminator One*	0.159	-0.249	0.634	-0.681	0.546	-0.493	0.639	-0.610
R.C.	*Snowboard with Comm*	0.279	-0.264	0.548	-0.518	0.513	-0.488	0.696	-0.656
	Oprah w/o Comm	0.136	-0.163	0.441	-0.397	0.458	-0.431	0.792	-0.739
	LectureHQ-Reisslein	0.004	-0.002	0.035	-0.024	0.125	-0.119	0.579	-0.555
	ParkingLot	0.166	-0.138	0.288	-0.236	0.336	-0.291	0.567	-0.491
CIF	*Silence of the Lambs*	0.024	-0.012	0.246	-0.1	0.61	-0.509	0.797	-0.674
128 kbps	*Terminator One*	0.016	-0.007	0.172	-0.118	0.536	-0.479	0.664	-0.627
R.C.	*Snowboard with Comm*	0.076	-0.05	0.264	-0.186	0.493	-0.464	0.699	-0.655
	Oprah w/o Comm	0.009	-0.006	0.076	-0.049	0.446	-0.409	0.803	-0.736
	LectureHQ-Reisslein	0.003	-0.005	-0.003	0	0.072	-0.066	0.549	-0.536
	ParkingLot	0.086	-0.074	0.223	-0.198	0.328	-0.284	0.577	-0.500
CIF	*Silence of the Lambs*	0	0	0.013	0.028	0.508	-0.415	0.817	-0.685
256 kbps	*Terminator One*	-0.005	0.018	0.052	-0.007	0.476	-0.417	0.682	-0.637
R.C.	*Snowboard with Comm*	0.011	-0.001	-0.006	0.03	0.434	-0.404	0.713	-0.664
	Oprah w/o Comm	0.003	-0.001	-0.046	0.049	0.338	-0.306	0.814	-0.741

Table 17: *continued*

LectureHQ-Reisslein	0.003	-0.006	-0.01	0.011	0.028	-0.022	0.543	-0.533
ParkingLot	0.012	-0.008	-0.014	0.036	0.298	-0.256	0.649	-0.564

Figures 32 and 33 give scatter plots of the tuples $(X_n,\ Q_n)$ and $(X_n^{(12)},\ Q_n^{(12)})$, respectively. For high quality *Silence of the Lambs* spatial encoded video, we find that most of the frames are in the range of 36-40 dB. For medium quality *Snowboard with Commercials* we notice a wider range of quality variation however now over a smaller frame sizes (because of the reduced quality level). This quality variation range is highest for low quality encoding of *Oprah without Commercials*.

For rate controlled sequence we notice that frame size quality tuples are concentrated over a smaller frame size range with a wide variation in quality levels (as was mentioned in earlier technical reports, rate control tries to achieve constant bit rate by varying frame quality) even though rate control is not effective for target bit rates of 64, 128, and 256 kbps.

Figure 34 gives the rate-distortion plots, i.e., the average video quality ($\bar{Q}$) as a function of the mean bit rate. The plots are obtained from the five different quality level encodings of the videos. The main point which should be observed here is that rate distortion plots do not have the same slope for different video sequences. The slope is not the same for base and enhancement layer for a given sequence encoded at a given encoding without rate control.

5 Conclusions

From the preceding analysis of the base layer, the enhancement layer, and the aggregated layer traffic, we observe a double hump in the coefficient of variation and peak-to-mean ratio centered at the 060810.Q and the medium quality level. This means that the video traffic at a particular quality level cannot be simulated by simply scaling the video traffic at other quality levels. This double hump in the CoV_X and the $X_{\max}/\bar{X}$ is to the best of our knowledge a new insight. For single layer encodings in the CIF format, the coefficient of variation exhibits double hump. However, single layer encodings in QCIF format exhibit only a single hump.

The long range dependence properties appear to be consistently strong for all quality levels of the videos encoded without rate control. In most of the cases, the Hurst parameter estimated from the R/S plot, the periodogram, and the variance time plot are the same for the base layer traffic and the enhancement layer traffic. This indicates that long range dependence is not changed by scaling the input video.

Most importantly, our traces of spatial scalable encoded videos provide realistic traffic data for evaluating the widely advocated networking scenario with a (nearly at 128kbps, and 256kbps) 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.

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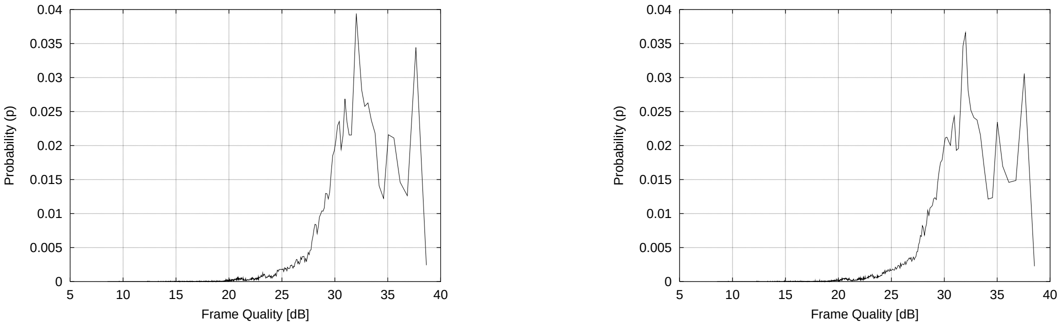
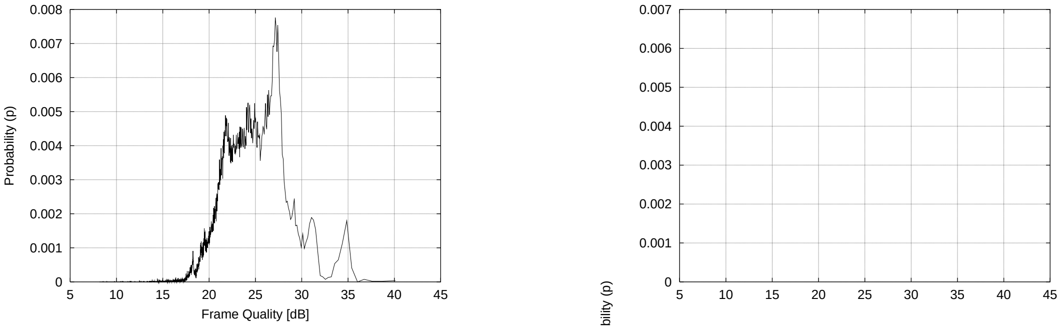


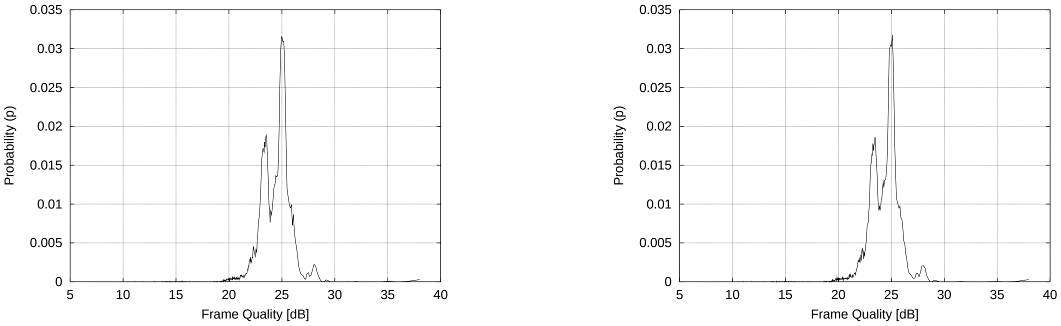
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



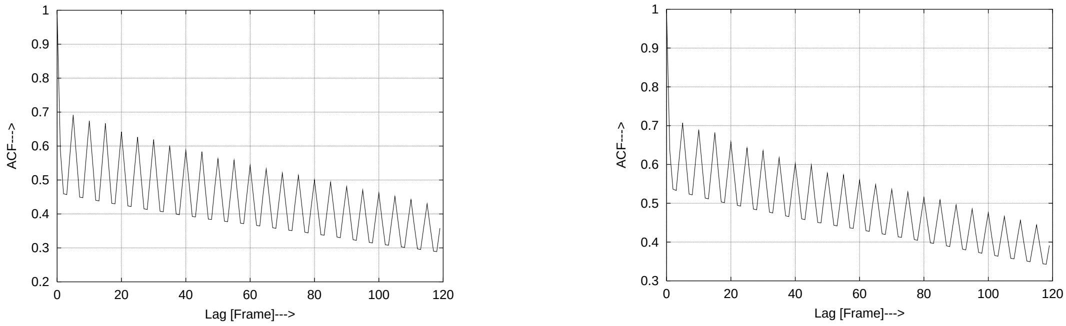
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

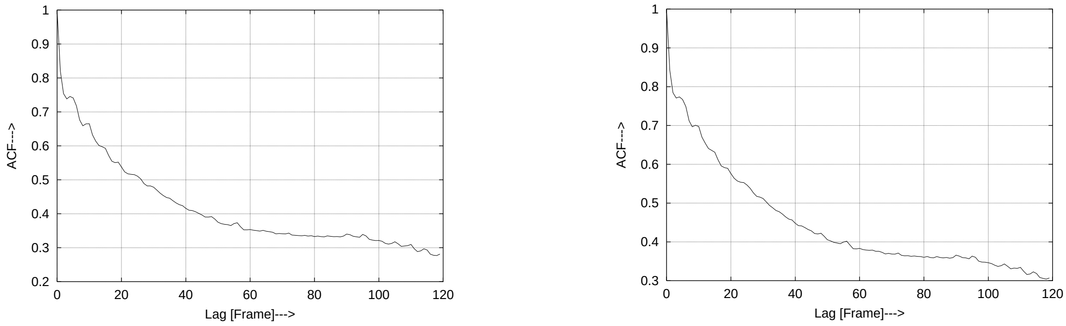
Encoding with rate control

Figure 25: Histograms of video frame quality Q_n^b (in dB) of the base layer of spatial scalable CIF video.



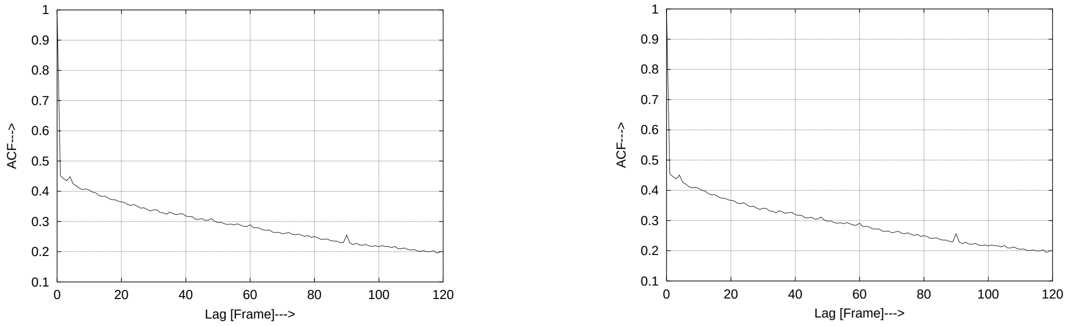
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



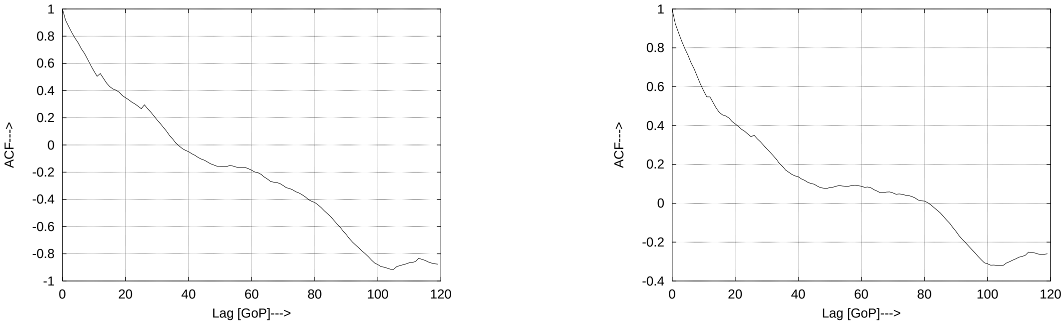
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

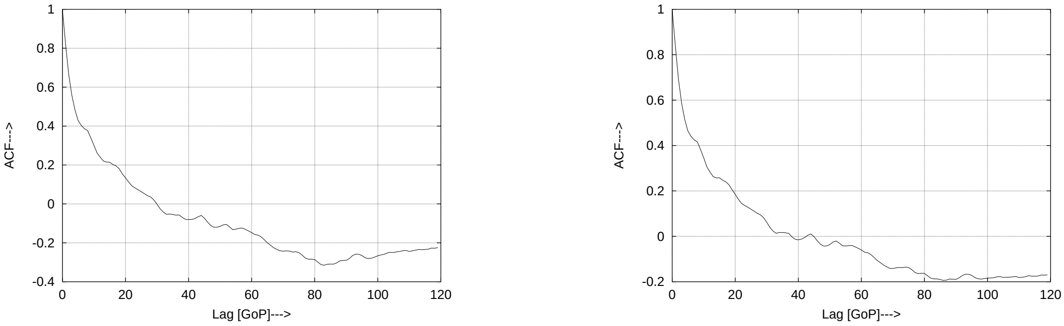
Encoding with rate control

Figure 26: MSE autocorrelation coefficient $\rho_M(k)$ as as function of the lag k (in frames) for the base layer of spatial scalable CIF video.



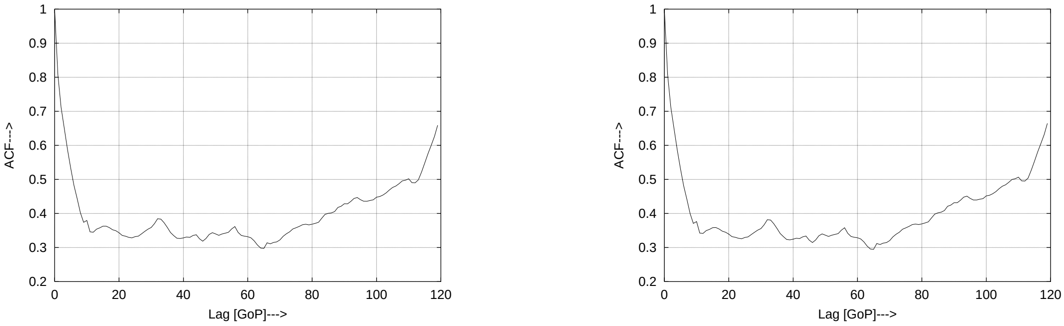
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



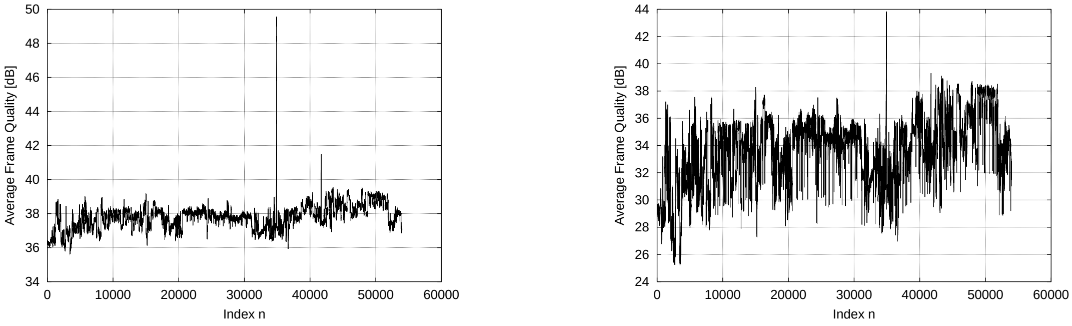
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

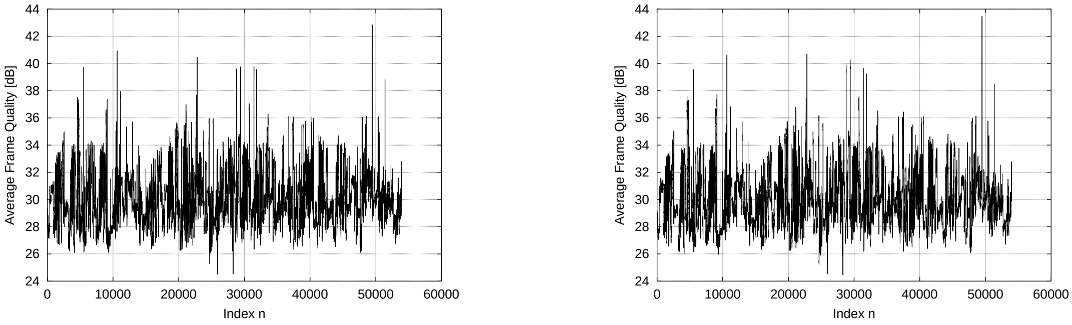
Encoding with rate control

Figure 27: MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of the lag k (in GoPs) for the base layer of spatial scalable CIF video.



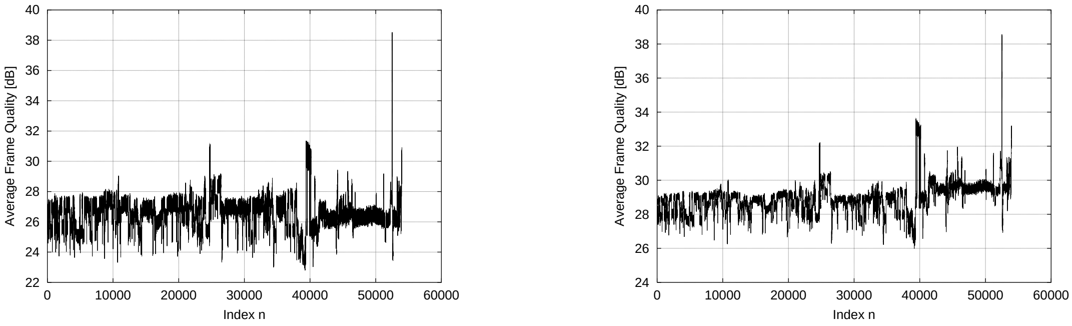
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



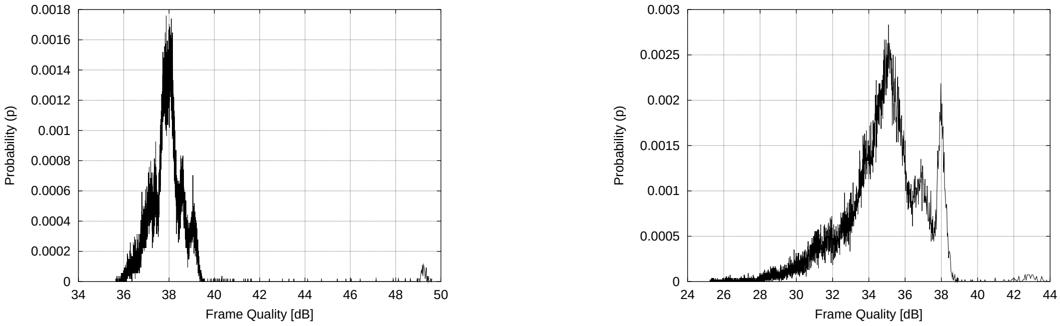
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

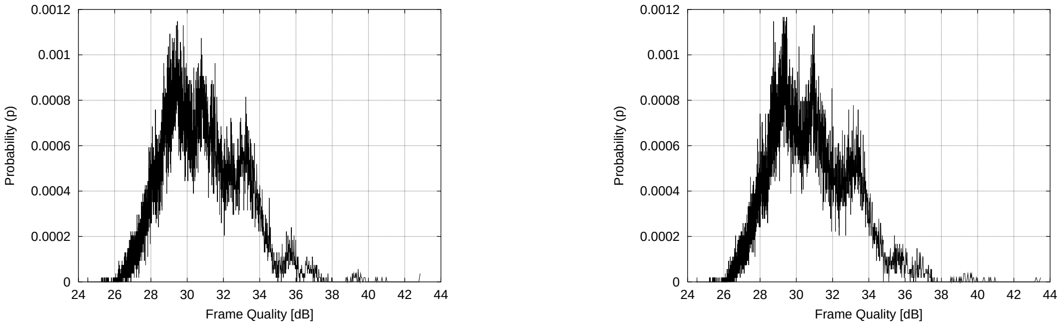
Encoding with rate control

Figure 28: Video frame quality Q_n^{agg} (in dB) as a function of the frame index n for the aggregate stream of spatial scalable CIF video.



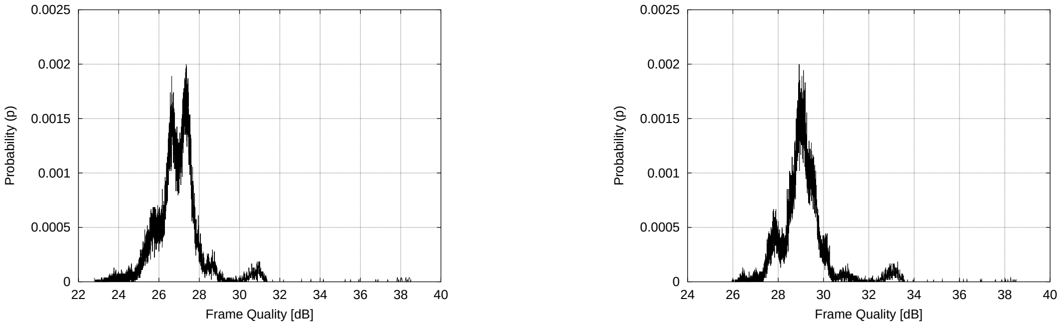
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



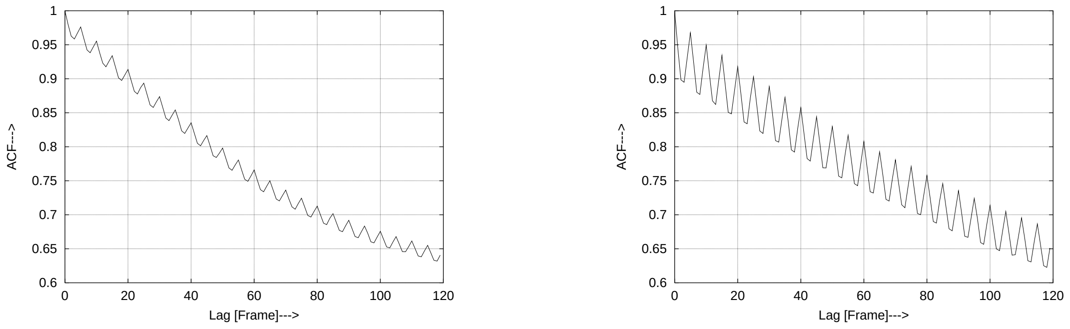
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

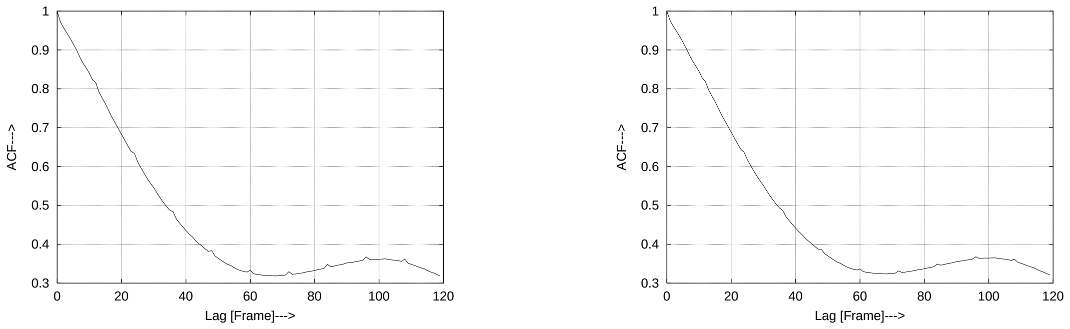
Encoding with rate control

Figure 29: Histograms of video frame quality Q_n^{agg} (in dB) of the aggregate stream of spatial scalable CIF video.



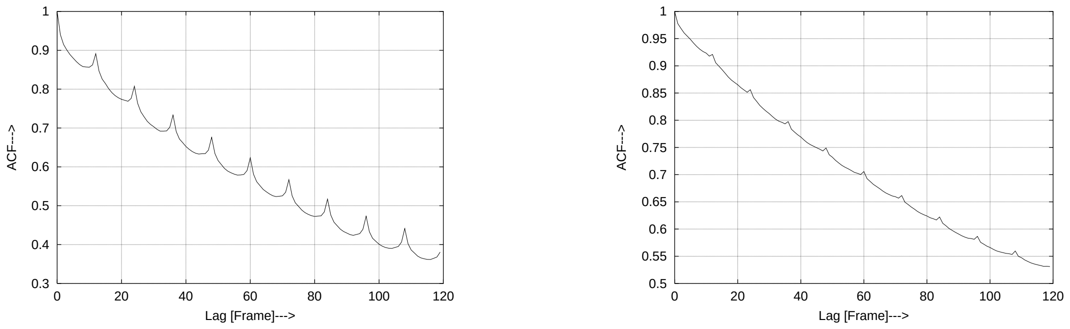
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



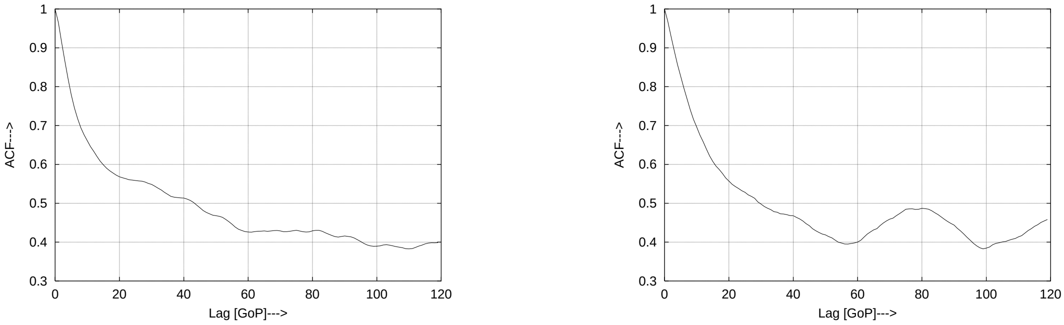
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

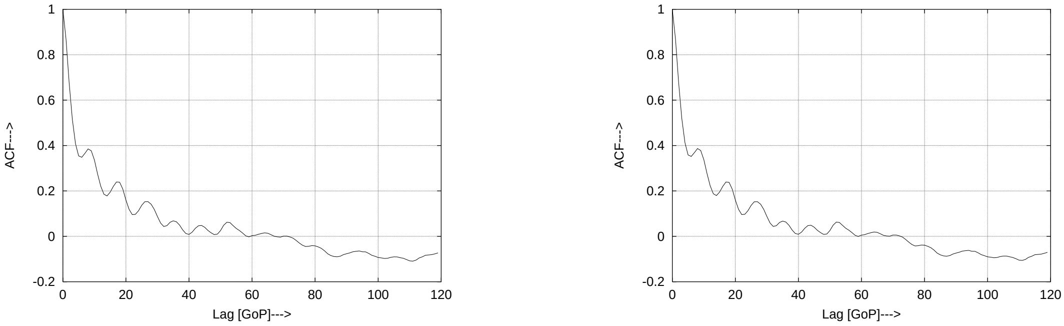
Encoding with rate control

Figure 30: MSE autocorrelation coefficient $\rho_M(k)$ as as function of the lag k (in frames) for the aggregate stream of spatial scalable CIF video.



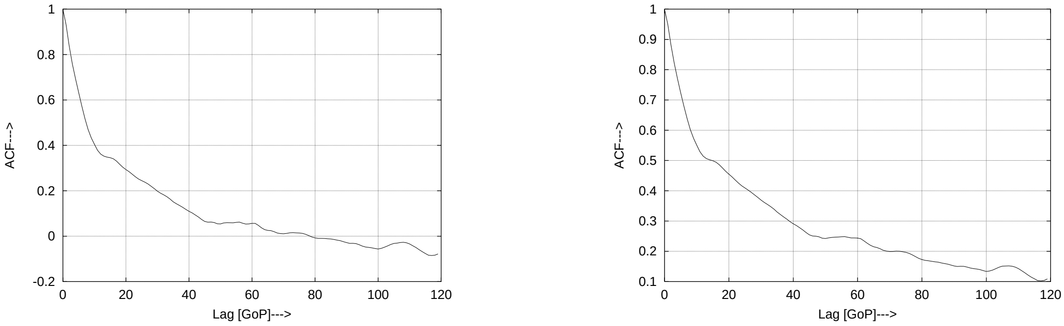
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



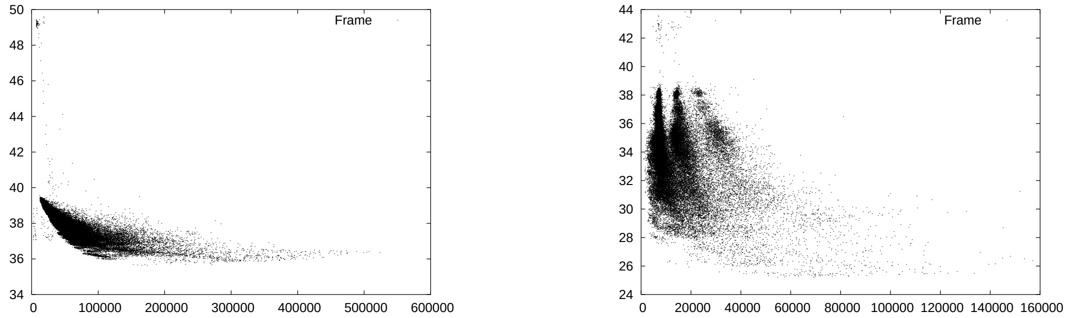
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

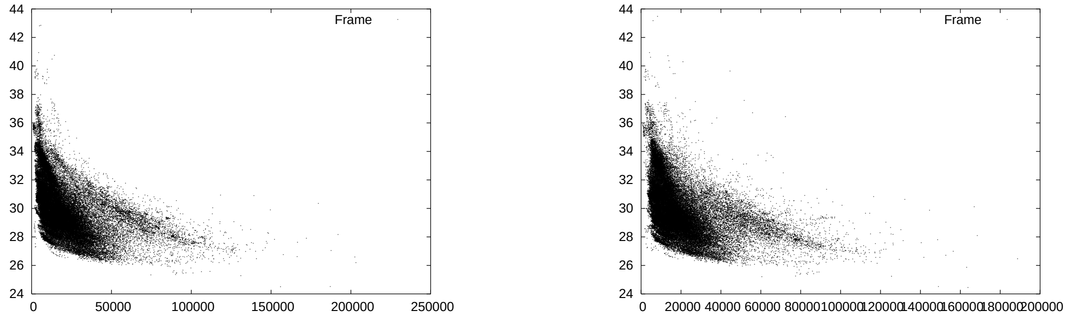
Encoding with rate control

Figure 31: MSE autocorrelation coefficient $\rho_M^{(G)}(k)$ as a function of the lag k (in GoPs) for the aggregate stream of spatial scalable CIF video.



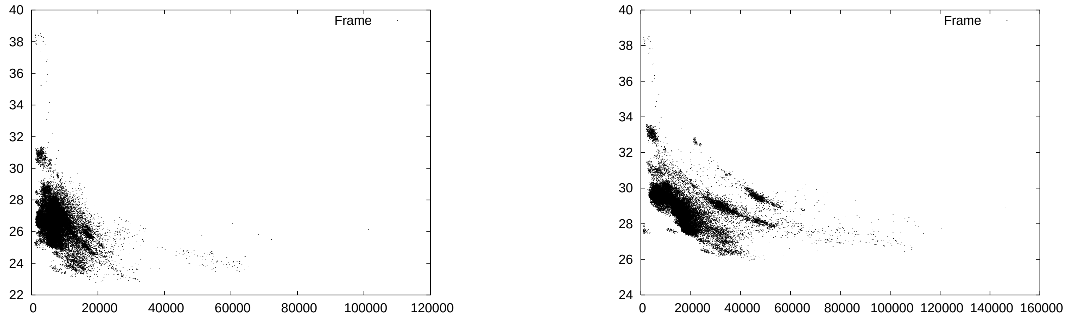
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



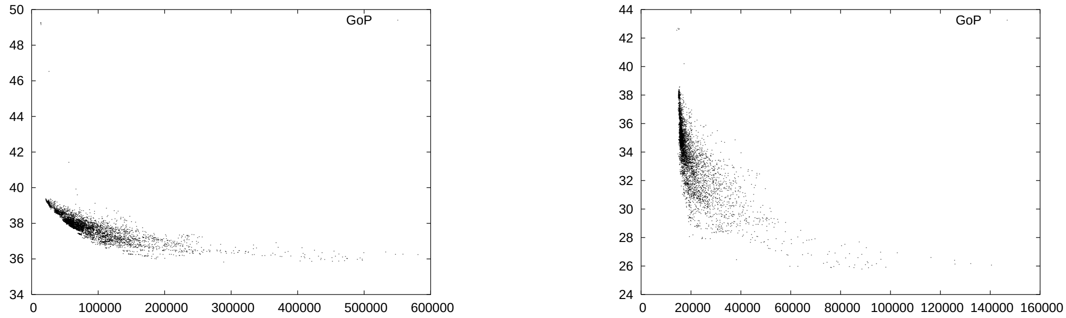
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

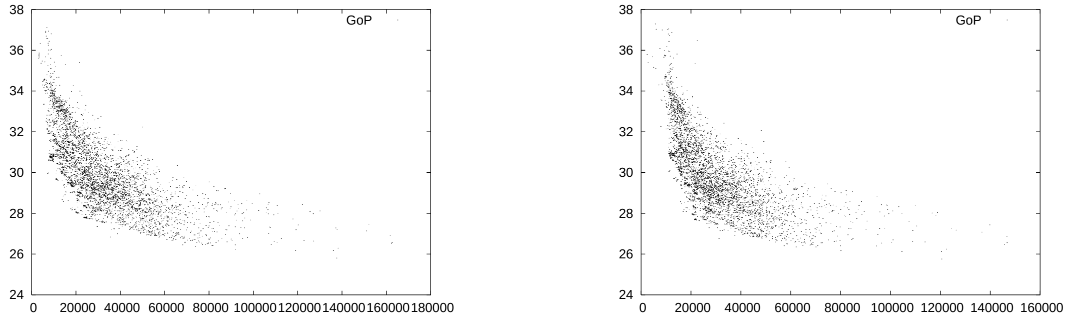
Encoding with rate control

Figure 32: Scatter plots of frame size and frame quality for aggregate stream of spatial scalable CIF video.



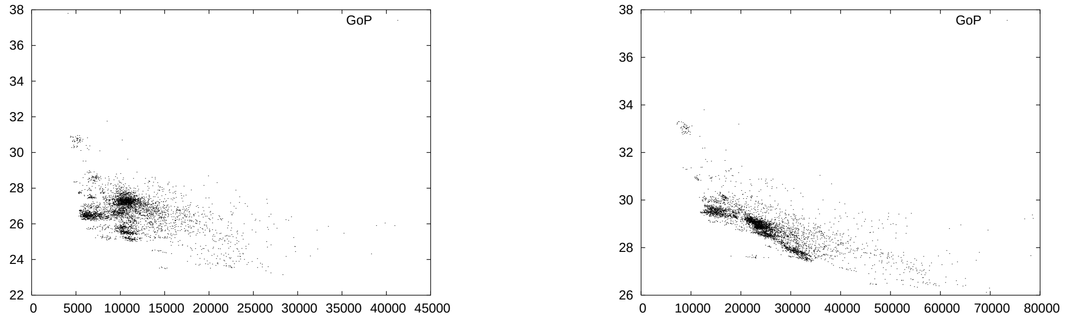
a) *Silence of the Lambs* with high quality

d) *Silence of the Lambs* with 256 kbps target bit rate



b) *Snowboard with Comm* with medium quality

e) *Snowboard with Comm* with 128 kbps target bit rate



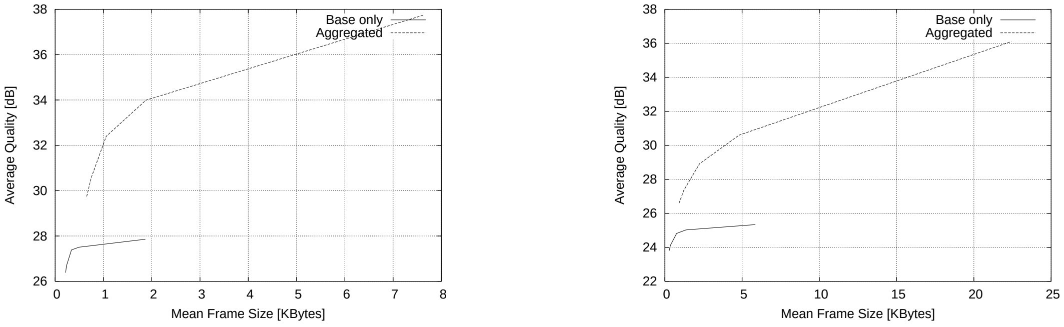
c) *Oprah w/o Comm* with low quality

f) *Oprah w/o Comm* with 64 kbps target bit rate

Encoding without rate control

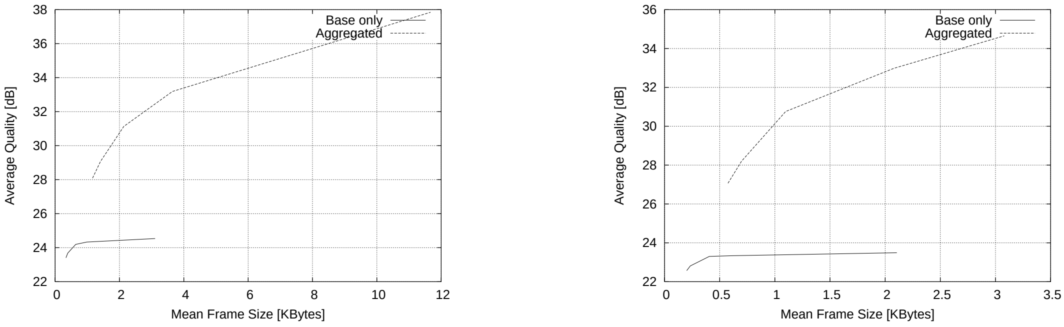
Encoding with rate control

Figure 33: Scatter plots of GoP size and average GoP quality for aggregate stream of spatial scalable CIF video.



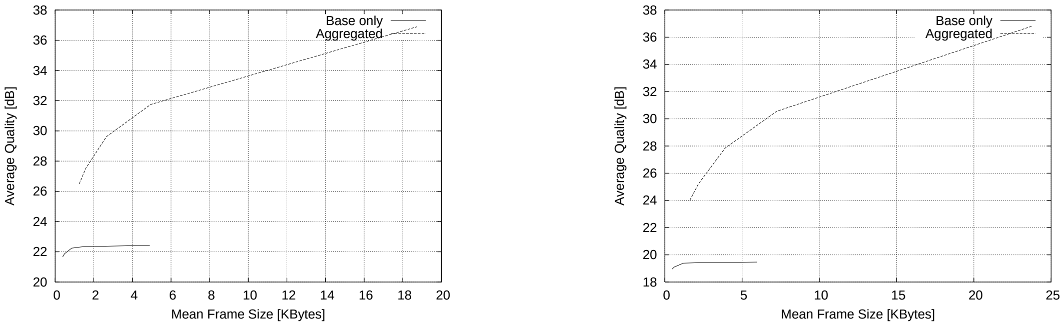
a) *Silence of the Lambs*

d) *Oprah w/o Comm*



b) *Terminator One*

e) *LectureHQ-Martin*



c) *Snowboard with Comm*

f) *Parking Lot*

Encoding without rate control

Encoding with rate control

Figure 34: Rate-distortion plots for aggregate stream of spatial scalable CIF video.