An Analysis of Constant Bitrate and Constant PSNR Video Encoding for Wireless Networks

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Abstract— **In wireless networks, transmission of constant-quality, high bitrate video is a challenging task due to channel capacity and buffer limitations. Content adaptive rate control, is used as a solution to this problem. Instead of transmitting all of the video content at low quality, the most important content can be transmitted at high quality while still preserving an acceptable quality for the remaining segments. Furthermore, the rate control strategy inside the individual temporal segments plays a key role for the network performance and viewing quality. Although constant quality video encoding inside the temporal segments is preferable for the best viewing experience, it causes more network packet losses due to adverse bitrate fluctuations in the video stream. In cases when the network is too much loaded, it may be better to employ constant bitrate encoding for network friendliness. In this paper, a performance analysis of constant bitrate and constant peak signal-to-noise ratio encoding for content adaptive rate controlled video streaming over wireless networks is presented. Experimental results obtained using AVC/H.264 encoding in a CDMA/HDR multi-user environment with cross-layer optimized scheduling show performance comparisons of CBR and CPSNR encoding.** [1]

I. INTRODUCTION

In low capacity wireless systems, video streaming at constant and satisfying quality is a very difficult task because of the unpredictable channel behavior in such schemes. The classical approach to rate control relies on the buffer management strategy of the codec system used. For example, the state-of-the-art video encoder AVC/H.264 [1] virtually tracks an exact replica of the decoder buffer at the encoder, called the Hypothetical Reference Decoder (HRD) [2] model. This enables the AVC/H.264 codec to guarantee continuous playout of the video at the receiving side given a fixed target encoding rate, a fixed channel throughput and the decoder buffer size. A similar approach is used in the MPEG standard, called the Video Buffer Verifier (VBV) [3] model. However, the fixed channel rate assumption of this approach is correct only if the network infrastructure provides guaranteed Quality-of-Service (QoS), which is not the case in most existing wireless services. Therefore, in the classical approach to video streaming, source coding and channel coding are thought of as two independent jobs, and the existing correlations between these can not be exploited for better system efficiency. On the other hand, in multi-user environments, both network efficiency and video quality can be considerably improved by considering network statistics in video encoding.

Another key point that can be considered in encoder rate control is the video content. Adverse channel variations in low-capacity wireless networks make it extremely difficult to deliver constantly high quality video. Content adaptive inter-temporal-segment rate control techniques for single-user video streaming have been proposed as a potential solution to this problem [4]. In addition to coding difficulty (scene complexity), importance of semantically defined temporal segments, i.e. group-of-pictures (GOP's), needs to be considered for bitrate control of the specific codec used. The GOP structure mentioned here has adaptive size depending on the content of the video and it can go up to an entire scene. We use the terms GOP and ”temporal segment” interchangeably in the remaining of this paper.

In content adaptive coding schemes, the video is first divided into GOP's with different semantic meaning. Each of these GOP's are categorized under a number of semantic classes. The temporal segments that are relatively more important according to the user (e.g. points taken, in-game strife etc. in a tennis game) are encoded at a higher average bitrate, compared to the less important temporal segments (e.g. breaks, audience shots etc.). The bitrate allocation strategy between semantically important and less important temporal segments may be either dictated by the user or determined by the server. On the other hand, the determination of intra-temporal-segment (inside the GOP) rate control strategy for the best network performance and viewing quality at the receiving side still remains to be an open issue in these types of schemes.

Modern video codecs like AVC/H.264 [1] can achieve very low bitrate coding of sequences. The use of such coders allows the distribution of video contents also on low-bandwidth links, like the ones involved in wireless communications. Unfortunately, the radio link suffers of wide bandwidth oscillations and, in particular at very low bitrates, concealment algorithms do not guarantee a satisfactory recovery of the eventually lost information, so degrading the perceived video quality. In those cases, it is preferable to recode the stream at lower quality, so

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avoiding losses, instead of keeping constant coding bitrate and relying on concealment techniques.

For the above reasons, adaptivity of video streams has been extensively studied in recent years. Some of these studies achieve bitrate adaptation via switching between previously encoded versions of the video content, which can be used for only video-on-demand applications. Scalable Video Coding (SVC) was introduced as an alternative solution, which has worse compression efficiency than the non-scalable schemes. Both of these rate control techniques can achieve a limited range of bitrates.

In video coding, the importance of video packets may differ from one to another due to semantic importance changes in the temporal direction, and also decodability of the resulting bitstream. Here, a packet is denoted as important in terms of decodability if a relatively bigger amount of distortion is introduced in the resulting bitstream in the absence of that packet. This variance of decodability importance is caused by the codec features such as inter and intra frame prediction. The overall user satisfaction can be significantly improved by using cross layer optimized packet scheduling with packet priority assignment and content (semantic relevance) analysis.

In this paper, a comparison of wireless streaming system performances using a modified AVC/H.264 codec with constant bitrate (CBR) and constant peak signal-to-noise ratio (CPSNR) encoding schemes for bitrate control inside the semantically defined GOP's is presented, and a mixture of the two schemes for network friendliness is proposed.

This paper is organized as follows: A discussion of CBR and CPSNR coding schemes with advantages and disadvantages is outlined in Section II. The multiple objective optimization (MOO) solution for optimal scheduling in 1xEV-DO is explained in Section III. The experimental results with different settings are given in Section IV, and finally, the conclusions are drawn in Section V.

II. BACKGROUND

As discussed in Section I, insufficient and varying network capacity may require the wireless service provider to adopt its video encoding on a GOP basis. Furthermore, if the user accesses the contents being charged on a per-byte basis, the user can desire to receive a low-quality stream when low-importance contents are played, and require higher quality encoding when the bitstream contains temporal segments considered as highly-important. The encoder may achieve this target by *i*) encoding GOP's at a higher or lower constant bitrate (CBR), or *ii*) encoding GOP's at a higher or lower constant PSNR (CPSNR), according to semantic importance, depending on the application. Techniques that optimize the choice on both of them jointly [5] exist in the literature .

A. GOP-Level Constant Bitrate (CBR) Control

In this part, we explain a modified rate control algorithm [6] for the state-of-the-art AVC/H.264 standard video codec (JM 9.3), which can achieve very impressive compression rates. The reference software implements a rate control algorithm, which requires the target rate value and a starting quantization parameter for the first I-frame of the sequence as its input. The output is a constant bitrate (CBR) sequence, which converges after a couple of GOP's and fluctuates around the selected bitrate for the remaining of the sequence. It is not possible to change the bitrate with this standard rate control algorithm while encoding. Even if this was possible, the convergence time of the standard rate control (multiple GOP's) would not allow changes at a required speed.

By means of modifying this rate control system to produce a single stream, encoded according to a per-GOP bitrate pattern, we can allow accurate channel throughput and content (user preferences) adaptation in real-time video communication. Here, the convergence speed is a key issue.

Changes in bitrate can obviously occur only when an I-frame is reached. As it is implemented in the reference codec, the GOP length is fixed by indicating the periodicity of I-frames and the number of B-frames in a run. The constraint on fixed GOP structure should be relaxed to gain more flexibility in this case. It is possible to modify the length of each GOP dynamically without affecting the decodability of the sequence, since the decoder is able to operate with any I-/P-/B-frame pattern, regardless of the structure of previous GOP's.

The encoder can receive the desired length of the GOP being coded from the content analyzer, so tuning also the position of I-frames. The codec stores internally some statistics on previous GOP's, which become useless, and meaningless, when the target rate is modified; those statistics need to be tuned accordingly.

To ensure faster bitrate convergence, in [6], we proposed initial quantization parameter re-computation for each GOP by dynamically updating quantization parameter (QP) vs. bits per pixel (*bpp*) table, in the duration of encoding. Every time a new I-frame is being coded, the desired bitrate is read and the target *bpp* indicator is computed according to the frame size and frame rate. The initial quantization parameter is then chosen from the table as the one ensuring the closer bpp indicator. Every time a GOP terminates, and right before starting the following I-frame, the bpp obtained for the last GOP is stored in the table together with its average quantization parameter, so updating the starting *static* values at each step to better fit over the sequence characteristics.

B. GOP-Level Constant Quality (CPSNR) Control

Constant quality coding is the dual approach of the constant bitrate, which tries to encode the video sequence at a given constant PSNR level without considering the resulting bitrate pattern. Despite its unsuitability for the network due to adverse bitrate variations it introduces, the constant quality approach is good for maximizing users' viewing experience.

To obtain a constant PSNR, a very simple approach is to set a constant quantization parameter (*QP*) for the duration of a shot. The problem with this approach is the lack of uniformity in the sequence content; i.e., the same quantizer level can lead to different PSNR's values if applied to different frames. However, usually a nearly constant PSNR can be obtained

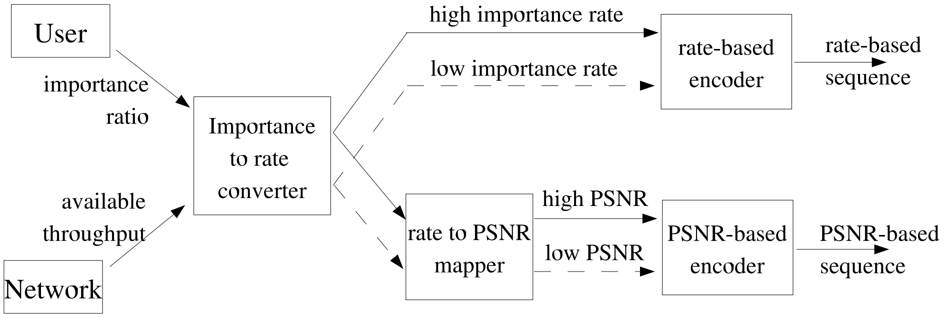

Fig. 1. CBR and CPSNR encoding scheme.

using a fixed QP on frames of a semantically defined temporal segment, due to similarity of video features.

In [7], QP is adapted in a per-frame basis in order to achieve constant quality encoding. The target PSNR value is compared with the average of the moving PSNR average over the last N frames at each frame encoding. If the difference is higher than a fixed threshold, the quantization parameter is changed. This will produce wider oscillations with respect to the constant QP approach, but the computational complexity of the control routine is negligible. This algorithm converges in few frames to the desired PSNR level with small fluctuation afterwards if the video content changes very fast as in the case of ”foreman”. The variance of the PSNR is around 0.3 for most sequences.

C. CBR vs. CPSNR

In *rate-distortion optimization* (RDO) [8], the coding parameters (coding modes, quantization) are chosen to reach a compromise between the bitrate and the quality. Usually, at high bitrate a further increase does not lead to noticeably better quality; on the other hand, at low bitrates, even a small variation in PSNR leads to relatively wide oscillation in the number of bits required. Joint decision can help in achieving the best choice.

RDO is especially useful when transmitting video sequences over packet data networks, since it results both in good network utilization and PSNR, given the video characteristics.

In constant bitrate (CBR) coding, the encoder does not take quality into account as long as it precisely matches the given target bitrate [9], [10]. Therefore, CBR encoding results in unwanted quality variance in the temporal direction. On the other hand, CBR encoding approach is necessary when transmitting the video over a fixed bitrate channel, or in general when oscillation in the bitrate could result in severe information losses or late delivery due to jitter increase.

The CBR and CPSNR encodings are done as shown in Figure 1. For CBR encoding, encoding rate ratios between semantically important and non-important segments are imposed by the user or set to default values by the server. These ratios along with the required average bitrate are given as an input to the *importance-to-rate converter* module. The output of this module dictates the modified CBR encoder rate control with the target bitrates for different shot types, resulting in the GOP-based CBR encoded bitstream. Given the target encoding rates for the high and low importance regions, it is possible to extract the corresponding rate-distortion behavior for a specific video content type. One can achieve this by experimenting with many instances of that content type and encoding all high and low importance shots at various rates to compute corresponding PSNR values. Similarly, the bitrate-PSNR mapping for soccer videos is found as shown in Figure 2 for soccer videos by averaging over a set of video shot instances. The *rate-to-PSNR mapper* module determines the target PSNR values for the high and low importance segments in this manner and these target rates are given as an input to the CPSNR encoder, resulting in the GOP-based CPSNR encoded bitstream.

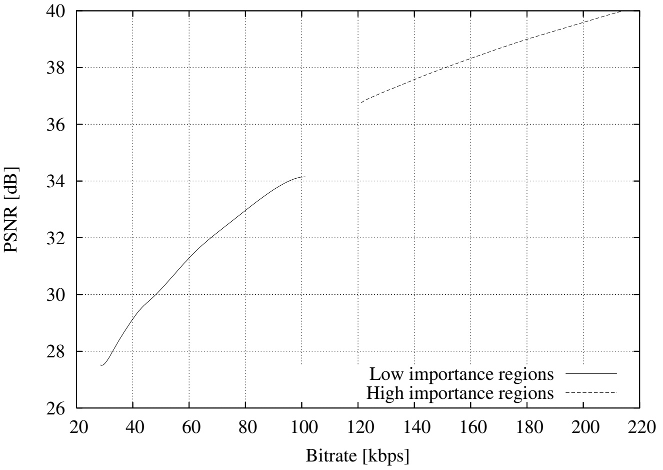

Fig. 2. Bitrate to PSNR mapping functions, for high and low importance regions.

III. OPTIMAL 1xEV-DO SCHEDULER

In wireless video transmission, service fairness is an important factor for determining the overall system performance along with delivered video quality and average channel throughput. For this reason, it is important to distribute system resources among users in such a way that they all utilize an equal share, also resulting in an equal viewing experience. The scheduling algorithm employed has a major effect on the communication system performance and must use information from multiple layers of the OSI protocol stack for better user experience, hence the cross-layer design. The semantic and decodability (concealment related) importance of video packets, which is helpful in assigning priorities to these packets, can be considered at the application layer.

The main objective of the wireless CDMA/HDR [11] High Data Rate scheme is to transmit packet data to multiple users with high speed. The 1xEV-DO (IS-856) [12] system used in this work is a CDMA/HDR standard, where opportunistic multiple access is employed and all transmission power is allocated to only one user in a time multiplexed manner. Adaptive channel coding and modulation are employed to support various data rates. It is crucial to choose an appropriate resource (time) scheduling algorithm to achieve the best system performance. Application layer requirements and physical layer limitations need to be well determined, and the scheduler has to be designed accordingly. For example, e-mail and SMS services are tolerant to delay, and intolerant to data loss, while real time streaming applications can tolerate few losses. Hence, cross-layer design is mandatory for video transmission, in order for a scheduling algorithm to be optimal in both physical and application layer aspects.

In [13], we introduced a multiple objective optimized (MOO) opportunistic multiple access scheme for user scheduling in a 1xEV-DO (IS-856) system, where the encoding rate control algorithm of [6] is employed. In this work, the user that experiences the best trade-off (best compromise) between the least buffer fullness, the best channel throughput and the highest video packet importance is scheduled, forcing the packet losses to occur at the low importance temporal segments. The problem formulation for such a multiple objective optimization (MOO) scheme is given as follows.

Schedule the user i at time slot t, such that:

$$argmax_i(R_i(t)) \tag{1}$$

$$argmin_i(B_i(t)) \tag{2}$$

$$argmax_i(imp_i(t)) \tag{3}$$

where $R_i(t)$, $B_i(t)$ and $imp_i(t)$ denote the channel throughput, decoder buffer occupancy level and the importance of the video packets in the server's transmission queue, respectively, for user i at time t as explained in [13].

Since the main application is real-time video streaming rather than a download-and-play scheme, video packets that are delivered later than their playout times need to be discarded at receiver side and considered lost. For this reason, the server may drop the packets that have passed their playout deadline at its transmission queue, avoiding unnecessary network traffic. For a more detailed explanation on the solution of such MOO problems, the readers are encouraged to see the related section in [13].

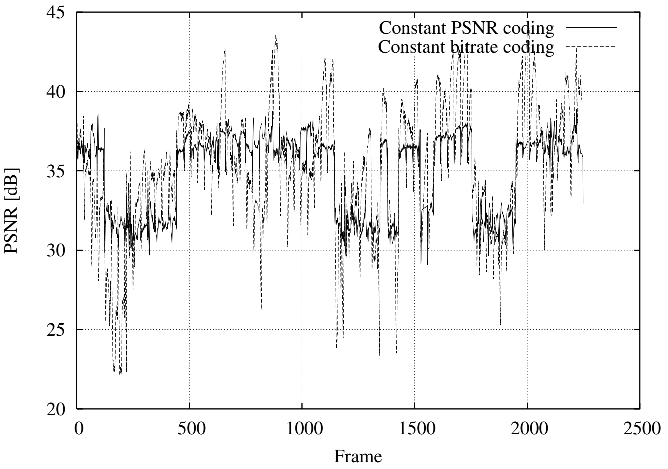

Fig. 3. PSNR graph for CBR and CPSNR encoding at 100 kbps with 1-to-2 bitrate ratio.

IV. EXPERIMENTAL RESULTS

For our experiments 90-second long (2250frames) test sequence (part of a soccer match) was encoded by assigning more bits to semantically more important regions than low-importance GOP's, with importance (bitrate) ratios 1-to-2 as shown in Table I and Table II. The resulting average encoding rate for the input video with QCIF spatial resolution and 25 fps temporal resolution is computed as 100 kbps . The GOP size is 30 frames with pattern IPPP...P, except for the last portions of the GOP's as the temporal segments need not to be an integer multiple of 30 frames. The physical layer simulations for the 1xEV-DO system have been carried out over the ITU Pedestrian A environment using the Advanced Design System (ADS-2004A) of Agilent Technologies. The decodability importance has been quantized using two levels. The decoder buffer size is assumed to be 2 Mbits, and the initial buffering (pre-roll) time and initial buffer build-up are limited to 10 seconds and 300 kbits, respectively. The users request the video from the server at random times uniformly distributed in the interval 0 to 7 seconds.

The resulting bitrate and PSNR functions for CBR and CPSNR encoding schemes are drawn in Figures 3 and 4. The arguments made in Section II can be observed from these figures more clearly. While the CBR encoding scheme provides nearly fixed encoding rate, it introduces much PSNR variation. The reverse is true for the CPSNR encoding scheme, i.e., while the PSNR is kept nearly constant within temporal segments, the bitrate behavior shows undesirable peaks.

Note that, in Table I we demonstrate the data for individual users where all users employ the CPSNR encoding, whereas Table II shows the case in which CPSNR and CBR encodings are used together in a network. The case where only CBR encoding is used is not shown in a separate table since there are no packet losses in that case. If we look at the packet loss percentages (PLR), these two tables indicate that the PLR values increase as more and more users request CPSNR encoding, resulting in lower average PSNR for the same

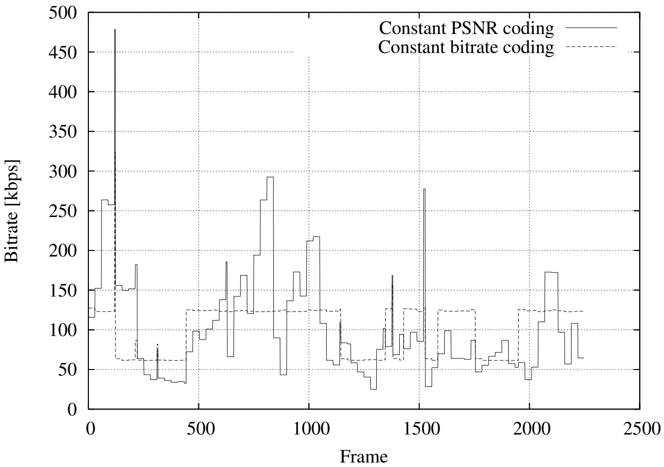

Fig. 4. Bitrate graph for CBR and CPSNR encoding at 100 kbps with 1-to-2 bitrate ratio.

number of users. When the users that request CBR and CPSNR encoding are mixed in the same system, it is observed that the ones that request CPSNR receive better video quality for approximately equal packet loss rate (see users 1 and 9 in Table III). The number of users that can be added to the system without excessive quality degradation depends on i) the rate at which they are being transmitted and ii) the definition of "acceptable degradation", which is beyond the scope of this paper.

V. CONCLUSION

In this work, a performance analysis for comparison of constant bitrate (CBR) and constant peak signal-to-noise ratio (CPSNR) video encoding for content adaptive rate control for wireless streaming is presented. Fast algorithms proposed for such rate control in the literature were reviewed and applied over a CDMA/HDR network, 1xEV-DO (IS-856) standard. Experimental results show that, the rate control strategy inside the individual temporal segments is a determining factor for the overall network performance and viewing quality. It was observed that, in cases where CPSNR and CBR encodings are done together within the same network, CPSNR scheme results in better video quality. The reason for this is that, the performance of users with CBR encoding are degraded by other CPSNR encoded bitstreams, due to adverse bitrate fluctuations. As a result, it is preferable to use CBR encoding when the network traffic is high and to use CPSNR encoding when there are few users in the network.

As future work, a cross-layer design for switching between constant bitrate and constant PSNR encoding schemes according to wireless channel conditions can be studied.

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TABLE I

ONLY CPSNR ENCODED VIDEOS REQUESTED BY ALL USERS.

user	Info				Importance								
	importance ratio	quantizer levels	environment	control technique	Overall			Low			High		
					bitrate	PLR	PSNR	bitrate	PLR	PSNR	bitrate	PLR	PSNR
1	1to2	2	ped	PSNR	100	5.70	33.69	61	9.49	30.22	122	4.40	35.70
2	1to2	2	ped	PSNR	100	1.00	34.58	61	.18	31.58	122	1.26	36.32
3	1to2	2	ped	PSNR	100	16.46	31.70	61	22.94	28.01	122	14.57	33.84
4	1to2	2	ped	PSNR	100	0	34.84	61	0	31.63	122	0	36.71
5	1to2	2	ped	PSNR	100	1.09	34.53	61	4.42	30.79	122	0	36.71
6	1to2	2	ped	PSNR	100	1.43	34.45	61	0	31.63	122	1.87	36.08
7	1to2	2	ped	PSNR	100	1.44	34.46	61	3.04	30.60	122	.89	36.69
8	1to2	2	ped	PSNR	100	4.52	33.65	61	10.23	30.05	122	3.51	35.72
9	1to2	2	ped	PSNR	100	8.99	33.41	61	7.46	29.95	122	9.42	35.42
10	1to2	2	ped	PSNR	100	2.43	34.13	61	.27	31.09	122	3.09	35.89
11	1to2	2	ped	PSNR	100	2.25	34.11	61	0	31.63	122	2.98	35.55
12	1to2	2	ped	PSNR	100	2.80	33.94	61	2.76	30.40	122	2.75	36.00

TABLE II

CBR AND CPSNR ENCODED VIDEOS REQUESTED BY DIFFERENT USERS.

user	Info				Importance								
	importance ratio	quantizer levels	environment	control technique	Overall			Low			High		
					bitrate	PLR	PSNR	bitrate	PLR	PSNR	bitrate	PLR	PSNR
1	1to2	2	ped	BR	100	5.09	33.74	61	5.82	31.11	122	6.60	35.25
2	1to2	2	ped	BR	100	0	34.45	61	0	31.14	122	0	36.38
3	1to2	2	ped	BR	100	3.60	33.51	61	3.41	30.28	122	3.73	35.37
4	1to2	2	ped	BR	100	.06	34.37	61	0	31.14	122	.08	36.24
5	1to2	2	ped	BR	100	.22	34.41	61	0	31.14	122	.28	36.31
6	1to2	2	ped	BR	100	4.64	33.68	61	0	31.14	122	6.00	35.16
7	1to2	2	ped	PSNR	100	0	34.84	61	0	31.63	122	0	36.71
8	1to2	2	ped	PSNR	100	2.56	34.22	61	4.20	30.32	122	1.97	36.48
9	1to2	2	ped	PSNR	100	6.76	33.64	61	6.02	29.83	122	6.94	35.85
10	1to2	2	ped	PSNR	100	.62	34.82	61	0	31.63	122	.82	36.67
11	1to2	2	ped	PSNR	100	0	34.84	61	0	31.63	122	0	36.71
12	1to2	2	ped	PSNR	100	.39	34.76	61	0	31.63	122	.52	36.57

TABLE III

BITRATE AND PSNR STATISTICS IN THE CASE OF CBR AND CPSNR ENCODING SCHEMES FOR 100 KBPS AVERAGE ENCODING RATE.

Imp. ratio	CBR based encoding								CPSNR based encoding							
	Low Imp.				High Imp.				Low Imp.				High Imp.			
	Bitrate		PSNR		Bitrate		PSNR		Bitrate		PSNR		Bitrate		PSNR	
	Mean	% err.	Mean	Var.	Mean	% err.	Mean	Var.	Mean	% err.	Mean	Var.	Mean	% err.	Mean	Var.
1to2	61.3	1.16	31.8	9.3	122.7	1.09	36.9	9.6	66.6	42.7	31.7	0.5	121.1	42.4	36.7	0.44
1to3	44.2	2.22	29.9	8.9	132.7	1.04	37.3	9.5	47.9	44.1	29.7	0.51	129.1	42.7	37.12	0.37
1to4	34.6	3.65	28.6	8.05	138.4	1.27	37.6	9.9	37.7	45.6	28.3	0.54	138.3	42.2	37.45	0.4
1to5	28.4	5.94	27.5	7.14	142	1.2	37.7	9.88	31.2	47.1	27.3	0.58	141.2	40.8	37.6	0.42