

Multiplexing Gain of Capped VBR Video

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1. Introduction

CBR (Constant Bit Rate) video fluctuates in quality, while its multiplexing behaviour is easy to predict: the links can be loaded to almost 100%. VBR (Variable Bit Rate) video aims at constant quality, but as the bit rate fluctuates over time the links cannot be fully loaded. Because in unconstrained VBR video the bit rate fluctuation might be too large, capped VBR video is proposed as an alternative. Similarly as for unconstrained VBR video, capped VBR video aims at a constant quality, but when in certain intervals this requires a too high bit rate, the bit rate is limited (i.e., capped) in order to support more video flows on the links, at the expense of a quality reduction.

2. Source model

Video flows can be bursty at various timescales. In this paper we assume that a shaping buffer in the video encoder or the video streamer smoothens the burstiness at all timescales below the scene timescale (e.g., the GoP (Group of Pictures), picture and packet timescale), which is easy to do at the expense of some delay. The burstiness at the scene timescale is hard to remove, as it would introduce too much delay (i.e., buffering a complete scene in a shaper would introduce a delay of the order of the duration of the scene). Under these assumptions a video source can be modelled as a Markov modulated fluid flow. The video source can be in either of K possible states. Each state corresponds to a scene type (with associated scene complexity). State changes are governed by a continuous-time Markov model with a given transition rate matrix, which typically is such that the average state sojourn times are between 2s and 10s [3].

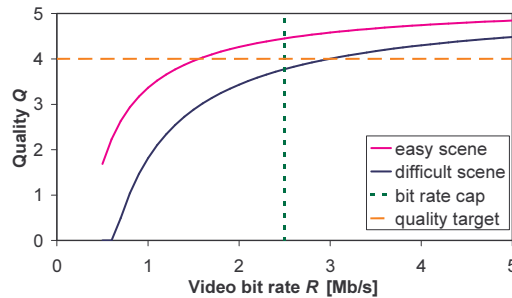


Figure 1: Quality Q versus video bit rate R for a difficult scene ($\chi_{Q,k}=0.045$) and an easy scene ($\chi_{Q,k}=0.025$).

With each state k a quality Q versus bit rate R trade-off is associated. Scenes with lots of motion and texture are far more difficult to encode (i.e., require a higher bit rate for the same quality) than quiet scenes with smooth areas. According to [4] this trade-off can be (approximately) described by

$$Q(R, k) = Q_{o,k} - \chi_{Q,k} \left(\frac{R}{\chi_{R,k}} \right)^{-1/\xi_{R,k}}, \quad (1)$$

where the parameters $Q_{o,k}$, $\chi_{Q,k}$, $\chi_{R,k}$, and $\xi_{R,k}$ determine how difficult scenes of type k are to compress. The quality rating Q takes values in the interval $[0,5]$, where 5 corresponds to excellent quality; a value below 3 indicates poor quality and a value 4 is typically aimed at. Inspired by the experiments in

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[4] we fix the parameters $Q_{o,k}$, $\chi_{R,k}$ and $\xi_{R,k}$ to 5.3, 125 and 1.11 respectively and let $\chi_{Q,k}$ change with the scene difficulty: $\chi_{Q,k}=(0.025+0.02k/(K-1))$ with $k=0, 1, \dots, K-1$. Figure 1 shows the Q versus R trade-off for the easiest and most difficult scene type. This figure shows that for CBR video encoded at 2.5Mb/s the quality Q fluctuates between 3.77 and 4.45, while for unconstrained VBR video targeted to have a constant quality $Q_{tgt}=4$ the bit rate R fluctuates between 1.56Mb/s and 3Mb/s. Capped VBR video with a target quality Q_{tgt} of 4 and a capping bit rate R_{cap} of 2.5Mb/s fluctuates over a smaller bit rate range than unconstrained VBR video, while the quality fluctuations are less than for CBR video. Remark that both CBR and unconstrained VBR are special cases of capped VBR: the former behaviour is reached when the target quality Q_{tgt} is set to 5 (in which case the capping rate R_{cap} is also the bit rate of the CBR video), while the latter behaviour results when the capping rate is set large enough for a given quality target Q_{tgt} .

3. Multiplexing model

To investigate how many of these video sources can be supported on an aggregation link of capacity C , we use the model of [1] (which is a large-number-of-sources approximation of the more generic method of effective bandwidth [2]). According to [1], the probability $P_o=\Pr[b>B]$ that the buffer occupancy b exceeds a threshold B is given by

$$P_o = \text{erfc} \left[\inf_{\tau>0} \left(\frac{B + C\tau - NA_R(\tau)}{\sqrt{NV_R(\tau)}} \right) \right], \quad (2)$$

where $A_R(\tau)$ and $V_R(\tau)$ are the average and variance respectively, of the information produced by one video source in an interval of length τ , N is the number of multiplexed sources and $\text{erfc}(x)$ is the one-sided tail distribution function of a zero-mean, unit-variance, Gaussian-distributed random variable. The stability condition is $N < (C\tau/A_R(\tau))$. The average $A_R(\tau)$ and variance $V_R(\tau)$ associated with a Markov modulated fluid source can be calculated based on the moment generating function given in [2]. For a transition rate matrix with all diagonal elements equal to $-1/T$ and equal off-diagonal elements (such that the average state sojourn times are all equal to T and such that at state change instants the system jumps from any state to any other state with equal probability), we have that

$$\begin{aligned} A_R(\tau) &= \frac{\sum_{k=0}^{K-1} R_k}{K} \tau = \bar{R} \tau, \\ V_R(\tau) &= \frac{\sum_{k=0}^{K-1} (R_k - \bar{R})^2}{K} \left(2 \frac{\exp(\lambda\tau) - \lambda\tau - 1}{\lambda^2} \right), \\ \bar{R} &= \frac{\sum_{k=0}^{K-1} R_k}{K}, \quad \lambda = - \left(\frac{K}{K-1} \right) \frac{1}{T}, \end{aligned} \quad (3)$$

where R_k is the rate produced by the source in state k (which depends on the value of Q_{tgt} and R_{cap}).

4. Results

To check the validity of the approximation made in Section 3, we first compare the analytical results with simulations performed with a C-based, event-driven simulator. The left part of Figure 2 displays traces obtained with the simulation program. It can be seen that when the overflow probability P_o to be estimated, is low, the required simulation time is large. The right part of Figure 2 illustrates that the results of the analytical prediction (of eq. (2)) only slightly underestimate the simulation results, which confirms the validity of the assumptions made in [1] and in Section 3.

The uninterrupted curves of Figure 3 show the trade-off involved when using capped VBR video at a target quality Q_{tgt} of 4. If the capping bit rate R_{cap} is set higher than 3Mb/s, the scenario boils down to the case of unconstrained VBR. If the capping bit rate R_{cap} is decreased below that value, the number

N of sources that can be multiplexed increases at the expense of a slight drop in average quality A_Q . If the capping bit rate R_{cap} decreases to a value below 1.5Mb/s the scenario boils down to the case of CBR.

Figure 3 also compares CBR (dashed curves) with capped VBR (uninterrupted curves). It can be seen that with capped VBR more sources can be multiplexed, at the expense of a slightly lower average quality, but the quality fluctuations are smaller.

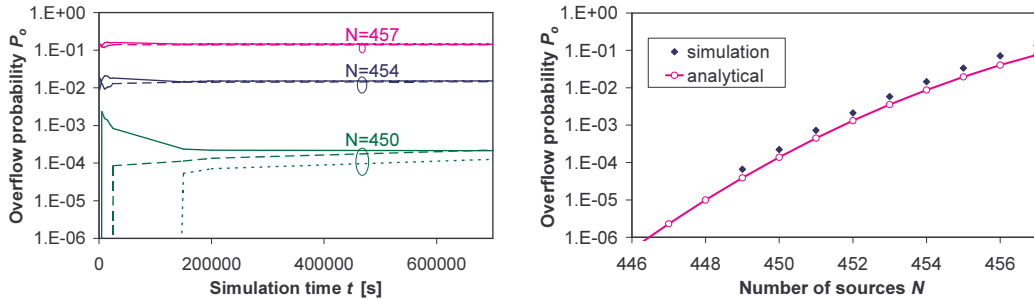


Figure 2: (left) Traces obtained with the simulation program (each trace corresponds to a different seed number for the random number generator) and (right) comparison of the analytical prediction of eq. (2) with simulation runs (of 700000s) for the case $K=10$, $T=5s$, $C=1Gb/s$, $B=1Mb$, $R_{cap}=2.5Mb/s$, $Q_{tgt}=4$.

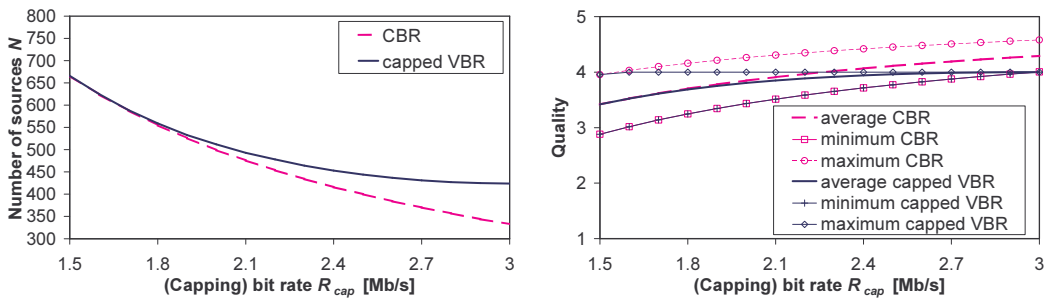


Figure 3: (left) Number of sources that can be supported on a link of capacity C and (right) average A_Q , minimum and maximum quality, both as a function of the (capping) bit rate (for the case $K=100$, $T=5s$, $C=1Gb/s$, $B=1Mb$, $P_o=10^{-6}$ and $Q_{tgt}=4$ in the capped VBR case).

5. Conclusion

Capped VBR has two parameters (i.e., the target quality Q_{tgt} and the capping bit rate R_{cap}) to tune, and hence, it inherently has additional flexibility. This paper showed that if these parameters are carefully tuned, capped VBR trades off the number of sources that can be multiplexed and video quality better than CBR and unconstrained VBR do.

References

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