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Title:	**Adaptive Basic Unit Layer Rate Control for JVT**
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1. Introduction

An encoder employs rate control as a way to regulate varying bit rate characteristics of the coded bitstream in order to produce high quality decoded frame at a given target bit rate. Rate control is thus a necessary part of an encoder, and has been widely studied in standards, like MPEG 2, MPEG 4, H.263, and so on [1,2,3,4,5]. However, it has not been well studied for JVT. The rate control for JVT is more difficult than those for other standards. This is because the quantization parameters are used in both rate control algorithm and rate distortion optimization (RDO), which resulted in the following chicken and egg dilemma when the rate control is studied: to perform RDO for macroblocks (MBs) in the current frame, a quantization parameter should be first determined for each MB by using the mean absolute difference (MAD) of current frame or MB [1,2,7,8]. However, the MAD of current frame or MB is only available after the RDO. Moreover, the available channel bandwidth for the coding process can be either constant or time varying. We thus need to consider both the constant bit rate (CBR) case and the variable bit rate (VBR) case. However, the existing schemes focus on the CBR case [1,2,3,4].

In this proposal, we present an adaptive basic unit layer rate control scheme for JVT by introducing a concept of basic unit and a linear model. The basic unit can be a frame, a slice, or an MB. The linear model is used to predict the MAD of current basic unit in the current frame by that of the basic unit in the co-located position of the previous frame. The chicken and egg dilemma is solved as follows: the target bit rate for the current frame is computed by adopting a leaky bucket model and linear tracking theory according to the predefined frame rate, the current buffer occupancy, the target buffer level and the available channel bandwidth [6]. The remaining bits are allocated to all non-coded basic units in the current frame equally because the MADs of non-coded basic units are not known. The MAD of current basic unit is predicted by the linear model using the actual MAD of basic unit in the co-located position of previous frame. A quadratic rate-distortion (R-D) model [1,2] is used to calculate the corresponding quantization parameter, which is then used for the rate distortion optimization for each MB in the current basic unit. We focus on the VBR case while our scheme performs equally well in the CBR case. A virtual buffer is used in our scheme to help adjust the coding process according to the dynamics of the channel bandwidth. The buffer is not underflowed nor overflowed. Since the model is almost the same as the leaky bucket model, our rate control is thus conformed to hypothetical reference decoder (HRD).

To verify our scheme, we test our scheme in both the VBR case and CBR case. The bit rate curve for the VBR case is a predefined curve. It is shown that the number of actual generated bits is kept close to the bit rate curve and the buffer is neither underflowed nor overflowed. For the CBR case, we compare the coding efficiency of an encoder by using our rate control scheme with that of an encoder using a fixed quantization parameter. The target bit rate is generated by coding a test sequence with a fixed quantization parameter. The computed rate is then specified in the encoder using our rate control scheme. The coding efficiency is improved by up to 1.02dB by our scheme, and the average PSNR of all testing sequences is improved by 0.32dB. We also compare our scheme with F086 recommended by AHG by using the software AHM2.0 [9][10]. The PSNR is improved by up to 1.73dB, the maximum loss is 0.25dB, and the average PSNR of all testing sequences as recommended by the AHG is improved by 0.5dB. It should be mentioned that our scheme is one pass while F086 is partially two pass.

2. Preliminary Knowledge

In this section, we shall present the problem associated with the rate control for H.264.

2.1 The Chicken and Egg Dilemma

The coding process of a MB related to the rate control is given by

$$\text{Rate Control} \rightarrow \text{Quantization Parameter} \rightarrow \text{RDO} \rightarrow \text{MAD} \rightarrow \text{Coding}$$

Since quantization parameters are specified in both rate control and RDO, there exists a problem when the rate control is implemented: to perform RDO for a MB, a quantization parameter should be first determined for the MB by using the MAD of MB. However, the MAD of current MB is only available after performing the RDO. This is a typical chicken and egg dilemma. Because of this, the rate control for H.264 is more difficult than those for MPEG 2, MPEG 4 and H.263. To study the rate control for H.264, we need to solve the problem to estimate the MAD of current MB. Besides this, we also need to compute a target bitrate for the current MB and to determine the number of contiguous MBs that share the same quantization parameter. To solve these problems, we need the following preliminary knowledge.

2.2 Definition of A Basic Unit

The concept of a basic unit is defined by

Definition 1 Suppose that a frame is composed of N_{mbpic} MBs. A basic unit is defined to be a group of contiguous MBs which is composed of N_{mbunit} MBs where N_{mbunit} is a fraction of N_{mbpic}.

Denote the total number of basic units in a frame by N_{unit}, which is computed by

$$N_{unit} = \frac{N_{mbpic}}{N_{mbunit}} \tag{1}$$

Examples of a basic unit can be an MB, a slice, a field, or a frame. For example, consider a video sequence with QCIF size, N_{mbpic} is 99. According to Definition 1,t N_{mbunit} can be 1, 3, 9, 11, 33, or 99. The corresponding N_{unit} is 99, 33, 11, 9, 3, and 1, respectively.

It is noted that by employing a bigger basic unit, a higher PSNR can be achieved while the bit fluctuation is also bigger. On the other hand, by using a small basic unit, the bit fluctuation is less severe, but with slight loss in PSNR.

2.3 A Fluid Flow Traffic Model

We shall now present a fluid flow traffic model to compute the target bit for the current coding frame. Let N_{gop} denote the total number of frames in a group of picture (GOP), $n_{i,j} (i = 1,2,\cdots, j = 1,2,\cdots, N_{gop})$ denote the jth frame in the ith GOP, and $B_c(n_{i,j})$ denote the occupancy of virtual buffer after coding the jth frame. We then have

$$B_c(n_{i,j+1}) = \min\{\max\{0, B_c(n_{i,j}) + A(n_{i,j}) - \frac{u(n_{i,j})}{F_r}\}, B_s\}$$
$$B_c(n_{1,1}) = \frac{B_s}{8} \qquad (2)$$
$$B_c(n_{i+1,0}) = B_c(n_{i,N_{gop}})$$

where A($n_{i,j}$) is the number of bits generated by the jth frame in the ith GOP, u($n_{i,j}$) is the available channel bandwidth which can be either a VBR or a CBR, F_r is the predefined frame rate, and B_s is the buffer size and its maximum value is determined based on different level and different profile [7].

Note that the initial buffer fullness is set at $B_s/8$. It can also be set at other value. Normally, the initial buffer fullness can be set at a low level if the bit fluctuation is very small.

The model is similar to the leaky bucket model in [7] in the sense that $F = 7B_s/8.$ In our design, we guarantee that the bitstream is contained in the above virtual buffer. Therefore, when the bitstream is input to an HRD with parameters $R = u, B = B_s$ and $F = 7B_s/8$, the HRD buffer does not overflow nor underflow. In other words, our rate control scheme is conformed to HRD.

2.4 A Linear Model for MAD Prediction

We now introduce a linear model to predict the MADs of current basic unit in the current frame by that of the basic unit in the co-located position of the previous frame. Suppose that the predicted MAD of current basic unit in the current frame and the actual MAD of basic unit in the co-located position of previous frame are denoted by $\mathrm{MAD}_{\mathrm{cb}}$ and MAD_{pb}, respectively. The linear prediction model is then given by

$$MAD_{cb} = a_1 * MAD_{pb} + a_2 \qquad (3)$$

where a_1 and a_2 are two coefficients of prediction model. The initial value of a_1 and a_2 are set to 1 and 0, respectively. They are updated after coding each basic unit. The linear model (3) is proposed to solve the chicken and egg dilemma.

With the concept of basic unit, models (2) and (3), the steps in our scheme are given as follows:

1. Compute a target bit for the current frame by using the fluid traffic model (2) and linear tracking theory [5].
2. Allocate the remaining bits to all non-coded basic units in the current frame equally.
3. Predict the MAD of current basic unit in the current frame by the linear model (3) using the actual MAD of basic unit in the co-located position of previous frame.
4. Compute the corresponding parameter by using the quadratic R-D model [1,2].
5. Perform RDO for each MB in the current basic unit by the quantization parameter derived from step 4 [7,8].

Our proposed rate control scheme is composed of two layers: GOP layer rate control and frame layer rate control if the basic unit is selected as a frame. Otherwise, an additional basic unit layer rate control should be added. They will be presented in detail in the following sections.

3. GOP Layer Rate Control

In this layer, we need to compute the total number of remaining bits T_r for all non-coded frames in each GOP and to determine the starting quantization parameter of each GOP. Same as [5], we assume that the GOP structure is IBBPBBP... P or IPPP…P, with I being an intra-coded picture, P being a forward predicted picture and B being a bi-directional predicted picture. The length of a GOP is usually 15-30 [4].

3.1 Total Number of Bits

In the beginning of the ith GOP, the total number of bits allocated for the ith GOP is computed as follows:

$$T_r(n_{i,0}) = \frac{u(n_{i,1})}{F_r} * N_{gop} - (\frac{B_s}{8} - B_c(n_{i-1,N_{gop}})) \qquad (4)$$

It can be shown from equation (4) that the coding results of the latter GOPs depend on those of the former GOPs. To ensure that all GOPs have a uniform quality, each GOP should use its own budget. In other words, the buffer occupancy should be kept at $B_s/8$ after coding each GOP. Since the channel bandwidth may vary at any time, T_r is updated frame by frame as follows:

$$T_r(n_{i,j}) = T_r(n_{i,j-1}) + \frac{u(n_{i,j}) - u(n_{i,j-1})}{F_r}(N_{gop} - j) - A(n_{i,j-1}) \qquad (5)$$

In the case of CBR, i.e. $u(n_{i,j}) = u(n_{i,j-1})$, Equation (5) is simplified as

$$T_r(n_{i,j}) = T_r(n_{i,j-1}) - A(n_{i,j-1}) \qquad (6)$$

In other words, Equation (5) is also applicable to the CBR case.

3.2 Starting Quantization Parameter of Each GOP

In our scheme, the starting quantization parameter of the first GOP is a predefined quantization parameter QP_0. The I frame and the first P frame of the GOP are coded by QP_0. QP_0 is predefined based on the available channel bandwidth and the GOP length. Normally, a small QP_0 should be chosen if the available channel bandwidth is high and a big QP_0 should be used if it is low. Under the same bandwidth, QP_0 reduces by 1 if the GOP length increases by 15.

The starting quantization parameter of other GOPs QP_{st} is computed by

$$QP_{st} = \frac{Sum_{PQP}}{N_p} - 1 - \frac{8T_r(n_{i-1,N_{gop}})}{T_r(n_{i,0})} - \frac{N_{gop}}{15} \qquad (7)$$

where N_p is the total number of P frame in the previous GOP and Sum_{PQP} is the sum of quantization parameters for all P frames in the previous GOP. Same as QP_0, QP_{st} is adaptive to the GOP length and the available channel bandwidth.

The I frame and the first P frame are coded using QP_{st}.

4. Frame Layer Rate Control

The frame layer rate control scheme consists of two stages: pre-encoding and post-encoding.

4.1 Pre-Encoding Stage:

The objective of this stage is to compute quantization parameter for all frames. We shall first provide a simple method to compute the quantization parameters of B frames.

4.1.1 Quantization parameters of B frames

Since B frames are not used to predict any other frame, the quantization parameters can be greater than those of their adjacent P or I frames such that the bits could be saved for I and P frames. On the other hand, to maintain the smoothness of visual quality, the difference between the quantization parameters of two adjacent frames should not be greater than 2. Based on the observations, the quantization parameters of B frames are obtained through a linear interpolation method as follows:

Suppose that the number of successive B frames between two P frames is L and the quantization parameters are QP_1 and QP_2, respectively. The quantization parameter of the ith B frame is calculated according to the following two cases:

Case 1. L=1. In other words, there is only one B frame between two P frames. The quantization parameter is computed by

$$Q\widetilde{B}_1 = \begin{cases} \frac{QP_1 + QP_2 + 2}{2} & \text{if } QP_1 \neq QP_2 \\ QP_1 + 2 & \text{Otherwise} \end{cases} \qquad (8)$$

Case 2 L>1. In other words, there are more than one B frame between two P frames. The quantization parameters are computed by

$$Q\widetilde{B}_i = QP_1 + \alpha + \max\{\min\{\frac{(QP_2 - QP_1)}{L-1}, 2(i-1)\}, -2(i-1)\} \qquad (9)$$

where α is the difference between the quantization parameter of the first B frame and QP_1, and is given by

$$\alpha = \begin{cases} -3 & QP_2 - QP_1 \leq -2L-3 \\ -2 & QP_2 - QP_1 = -2L-2 \\ -1 & QP_2 - QP_1 = -2L-1 \\ 0 & QP_2 - QP_1 = -2L \\ 1 & \mathrm{QP}_2 - QP_1 = -2L+1 \\ 2 & \text{Otherwise} \end{cases} \qquad (10)$$

The case that $QP_2 - QP_1 < -2L+1$ can only occur at time instant the video sequence switches from one GOP to another GOP.

The final quantization parameter QB_i is further adjusted by

$$QB_i = \min\{\max\{Q\widetilde{B}_i, 1\}, 51\} \qquad (11)$$

4.1.2 Quantization Parameters of P Frames

The quantization parameters of P frames are computed via the following two steps:

Step 1 Determine a target bit for each P frame. Step 1 is composed of the following two sub-steps.

Step 1.1 Macroscopic control (budget allocation among pictures).

The bit allocation is implemented by predefining a target buffer level for each P picture. The function of target buffer level is to compute a target bit for each P frame, which is then used to compute the quantization parameter. Since the quantization parameter of the first P frame is given at the GOP layer, we only need to predefine target buffer levels for other P frames in each GOP. After coding the first P frame in the ith GOP, we reset the initial value of target buffer level as

$$Tbl(n_{i,2}) = B_c(n_{i,2}) \qquad (12)$$

where $B_c(n_{i,2})$ is the actual buffer occupancy after coding the first P frame in the ith GOP.

The target buffer level for the subsequent P frames is determined by

$$Tbl(n_{i,j+1}) = Tbl(n_{i,j}) - \frac{Tbl(n_{i,2}) - B_s/8}{N_p - 1} + \frac{\widetilde{W}_p(n_{i,j})(L+1)u(n_{i,j})}{F_r(\widetilde{W}_p(n_{i,j}) + \widetilde{W}_b(n_{i,j})L)} - \frac{u(n_{i,j})}{F_r} \qquad (13)$$

where $\widetilde{W}_p(n_{i,j})$ is the average complexity weight of P pictures, $\widetilde{W}_b(n_{i,j})$ is the average complexity weight of B pictures, and $Tbl(n_{i,j})$ is the target buffer level. $\widetilde{W}_p$ and $\widetilde{W}_b$ are computed by

$$\begin{aligned}
\widetilde{W}_p(n_{i,j}) &= \frac{W_p(n_{i,j})}{8} + \frac{7*\widetilde{W}_p(n_{i,j-1})}{8} \\
\widetilde{W}_b(n_{i,j}) &= \frac{W_b(n_{i,j})}{8} + \frac{7*\widetilde{W}_b(n_{i,j-1})}{8} \\
W_p(n_{i,j}) &= S_p(n_{i,j})Q_p(n_{i,j}) \\
W_b(n_{i,j}) &= \frac{S_b(n_{i,j})Q_b(n_{i,j})}{1.3636}
\end{aligned} \qquad (14)$$

S_p and S_b are the number of bits generated by encoding the corresponding frame, and Q_p and Q_b are the corresponding quantization parameters.

In the case that there is no B frame between two P frames, Equation (13) can be simplified as

$$Tbl(n_{i,j+1}) = Tbl(n_{i,j}) - \frac{Tbl(n_{i,2}) - B_s/8}{N_p - 1} \tag{15}$$

It can be easily shown that $Tbl(n_{i,N_{gop}})$ is about $B_s/8$. Thus, if the actual buffer fullness is exactly the same as the predefined target buffer level, it can be ensured that each GOP uses its own budget. However, since the rate-distortion (R-D) model and the MAD prediction model are not accurate [1,2], there usually exists a difference between the actual buffer fullness and the target buffer level. We therefore need to compute a target bit for each frame to reduce the difference between the actual buffer fullness and the target buffer level. This is achieved by the following microscopic control.

Step 1.2 Microscopic control (target bit rate computation).

Using linear tracking theory [6], the target bits allocated for the jth frame in the ith GOP is determined based on the target buffer level, the frame rate, the available channel bandwidth and the actual buffer occupancy as follows:

$$\tilde{f}(n_{i,j}) = \frac{u(n_{i,j})}{F_r} + \gamma(Tbl(n_{i,j}) - B_c(n_{i,j})) \tag{16}$$

wherein γ is a constant and its typical value is 0.75 when there is no B frame and 0.25 otherwise. If the actual number of generated bits is around the target, it can be easily shown that

$$B_c(n_{i,j+1}) - Tbl(n_{i,j+1}) \approx (1-\gamma)(B_c(n_{i,j}) - Tbl(n_{i,j})) \tag{17}$$

Therefore, a tight buffer regulation can be achieved by choosing a large γ.

Meanwhile, the number of remaining bits should also be considered when the target bit is computed.

$$\hat{f}(n_{i,j}) = \frac{W_p(n_{i,j-1})T_r(n_{i,j})}{W_p(n_{i,j-1})N_{p,r}(j-1) + W_b(n_{i,j-1})N_{b,r}(j-1)} \tag{18}$$

The target bit is a weighted combination of $\tilde{f}(n_{i,j})$ and $\hat{f}(n_{i,j})$:

$$f(n_{i,j}) = \beta * \hat{f}(n_{i,j}) + (1-\beta) * \tilde{f}(n_{i,j}) \tag{19}$$

wherein β is a constant and its typical value is 0.5 when there is no B frame and is 0.9 otherwise.

Step 2 Compute the quantization parameter and perform RDO.

The MAD of current P frame is predicted by model (2) using the actual MAD of previous P frame. The quantization parameter $\hat{Q}_{pc}$ corresponding to the target bit is then computed by using the quadratic model provided in [1,2]. The details on this can be found in [1,2,5], it is thus not elaborated in this section. To maintain the smoothness of visual quality among successive frames, the quantization parameter $\tilde{Q}_{pc}$ is adjusted by

$$\tilde{Q}_{pc} = \min\{Q_{pp} + 2, \max\{Q_{pp} - 2, \hat{Q}_{pc}\}\} \quad (20)$$

where Q_{pp} is the quantization parameter of the previous P frame.

The final quantization parameter Q_{pc} is further bounded by

$$Q_{pc} = \min\{51, \max\{\tilde{Q}_{pc}, 1\}\} \quad (21)$$

The quantization parameter is then used to perform RDO for each MB in the current frame by using the method provided in [7,8]. The coding mode is selected by minimizing the following performance index:

$$D(s,c,MODE \mid QP) + \lambda_{mode} R(s,c,MODE \mid QP) \quad (22)$$ with

$$\begin{aligned} \lambda_{mode} &= 0.85 \times 2^{QP/3}, && \text{for I, P pictures;} \\ \lambda_{mode} &= 4 \times 0.85 \times 2^{QP/3}, && \text{for B pictures.} \end{aligned} \quad (23)$$

If the picture is P or B and the SAD is adopted as the criterion, the lambda in motion estimation is give by

$$\lambda_{motion} = \sqrt{\lambda_{mode}} \quad (24)$$

4.2 Post-encoding Stage:

There are three major tasks in this stage: update the parameters a_1 and a_2 of model (3), the parameters of quadratic R-D model, and determine the number of frames needed to be skipped. After encoding a picture, the parameters of model (3), as well as those of quadratic R-D model are updated. A method similar to that of R-D model in [1,2] is used where the window size is computed by using the method provided in [5] instead of that in [1,2].

After encoding a frame, the actual of bits generated, A($n_{i,j}$) is added to the current buffer occupancy. To ensure that the updated buffer occupancy is not too high, the frame skipping parameter N_{post} is set to zero and increased until the following buffer condition is satisfied [1]:

$$B_c(n_{i,j+N_{post}}) < B_s * 0.8 \qquad (25)$$

wherein the buffer fullness is updated as follows:

$$B_c(n_{i,j+l+1}) = B_c(n_{i,j+l}) - u(n_{i,j+l}) / F_r ; 1 \le l < \mathrm{N}_{\mathrm{post}} \qquad (26)$$

5. Basic Unit Layer Rate Control

If the basic unit is not selected as a frame, an additional basic unit layer rate control should be added to our scheme.

Same as the frame layer rate control, the I frame is coded by single quantization parameter. It is computed in the same way as that at frame layer. The B frame is also coded by single quantization parameter. It is computed almost the same as that at the frame layer provided that QP_1 and QP_2 are replaced by the average values of quantization parameters of all basic units in the corresponding frame.

In the remaining part of this section, we shall provide the basic unit layer rate control for each P frame.

Same as the frame layer, we shall first determine the target bit for each P frame. The process is the same as that at the frame layer. The bits are then allocated to each basic unit. Since the MADs of all non-coded basic units in the current frame are not known, we allocate the remaining bits to all non-coded basic units in the current frame equally.

The basic unit layer rate control selects the values of quantization parameters of all basic units in a frame, so that the sum of generated bits is close to the frame target $f(n_{i,j})$.

The following is a step-by-step description of this method.

Step 1 Compute the number of texture bits $R_{t,l}$ for the current basic unit. This step is composed of the following three substeps:

Step 1.1 Compute the target bit for the current basic unit.

Let $f_{rb}(n_{i,j})$ and N_{ub} denote the number of remaining bits for the all non-coded basic unit in the current frame and the number of non-coded basic units, respectively. The initial values of $f_{rb}(n_{i,j})$ and N_{ub} are $f(n_{i,j})$ and N_{unit}, respectively. The target bit for the current basic unit is given by f_{rb} / N_{ub}.

Step 1.2 Compute the average number of header bits generated by all coded basic units:

$$\begin{aligned} \widetilde{m}_{hdr,l} &= \widetilde{m}_{hdr,l-1}(1-\frac{1}{l}) + \frac{\hat{m}_{hdr,l}}{l} \\ m_{hdr} &= \widetilde{m}_{hdr,l}\frac{l}{N_{unit}} + m_{hdr,1}(1-\frac{l}{N_{unit}}) \end{aligned} \tag{27}$$

where $\hat{m}_{hdr,l}$ is the actual number of header bits generated by the lth basic unit in the current frame, $m_{hdr,1}$ is the estimate from all basic units in the previous frame.

Step 1.3 Compute the number of texture bits $R_{t,l}$.

$$R_{t,l} = \frac{f_{rb}}{N_{ub}} - m_{hdr} \tag{28}$$

Step 2 Predict the MAD of current basic unit in the current frame by model (3) using the actual MAD of basic unit in the same position of previous frame.

Step 3 Compute the quantization parameter of current basic unit by using the quadratic R-D model. We need to consider the following three cases:

Case 1 The first basic unit in the current frame.

$$Q_{cb} = Q_{apf} \tag{29}$$

where Q_{apf} is the average value of quantization parameters for all basic units in the previous frame.

Case 2 $f_{rb} < 0$. In this case, the quantization parameter should be greater than that of previous basic unit such that the sum of generated bits is close to $f(n_{i,j})$, i.e.

$$\hat{Q}_{cb} = Q_{pb} + DQuant \quad (30)$$

where Q_{pb} is the quantization parameter of previous basic unit. To reduce the blocking artifacts, $DQuant$ is 1 if N_{unit} is greater than 8 and is 2 otherwise.

To maintain the smoothness of visual quality, the quantization parameter is further bounded by

$$Q_{cb} = \max\{1, Q_{apf} - \Delta, \min\{51, Q_{apf} + \Delta, \hat{Q}_{cb}\}\} \quad (31)$$

where Δ is 3 if N_{mbunit} is less than the total number of MBs in a row, and 6 otherwise.

Case 3 Otherwise. In this case, we shall first compute a quantization parameter $\hat{Q}_{cb}$ by using the quadratic model. Similar to case 2, it is bounded by

$$\tilde{Q}_{cb} = \max\{Q_{pb} - DQuant, \min\{\hat{Q}_{cb}, Q_{pb} + DQuant\}\} \quad (32)$$

The objective is to reduce the blocking artifacts. Meanwhile, to maintain the smoothness of visual quality, it is further bounded by

$$Q_{cb} = \max\{1, Q_{apf} - \Delta, \min\{51, Q_{apf} + \Delta, \tilde{Q}_{cb}\}\} \quad (33)$$

Step 4 Perform RDO for all MBs in the current basic unit.

Step 5 Update the number of remaining bits and the number of non-coded basic units for the current frame.

Step 6 After coding a whole frame, Q_{apf} is updated.

To obtain a good trade-off between average PSNR and bit fluctuation, N_{mbunit} is recommended to be the number of MBs in a row for real time video communication, and N_{unit} is recommended to be 9 for other applications.

Comment: To reduce the number of bits used for the difference among the quantization parameters of MBs, the syntax of H.264 could be modified by inserting a flag in the beginning of the bit stream to indicate the exact number of MBs in the basic unit. We then only need to code the difference among the quantization parameters of basic unit instead of those of MBs.

6. Experimental Results

We test our rate control scheme in both the VBR case and the CBR case. RDO is ON when the frame type is IPBBP and it is off when the frame type is IPPP.

Group 1 Variable bit rate (VBR)

Test conditions are given in Table 1. The test platform is JM6.1; Test sequences: News, Foreman, Container, Coastguard, and Silent; Format: QCIF(4:2:0); Input frame rate is 30 f/s, encoded frame rate is 15f/s; QP for the first I picture is 21; Bandwidth: 128000 bits/s ($1 \le j \le 60$), 192000 bits/s ($61 \le j \le 150$).

MV resolution	1/4 pel
Hadamard	ON
RD optimization	Off
Search Range	±16 (QCIF), ±32 (CIF)
Restrict Search Range	2
Reference Frames	1
Symbol Mode	CABAC
GOP structure	IPP
Framestobeencoded	150

Table 1 Test Conditions

The experimental results for the sequences are given in the following Figures 1-5 and Table 2. It is shown that the actual generated bits are closed to their target bit rate and the actual buffer is kept close to its target buffer level. Moreover, the buffer is neither underflow nor overflow.

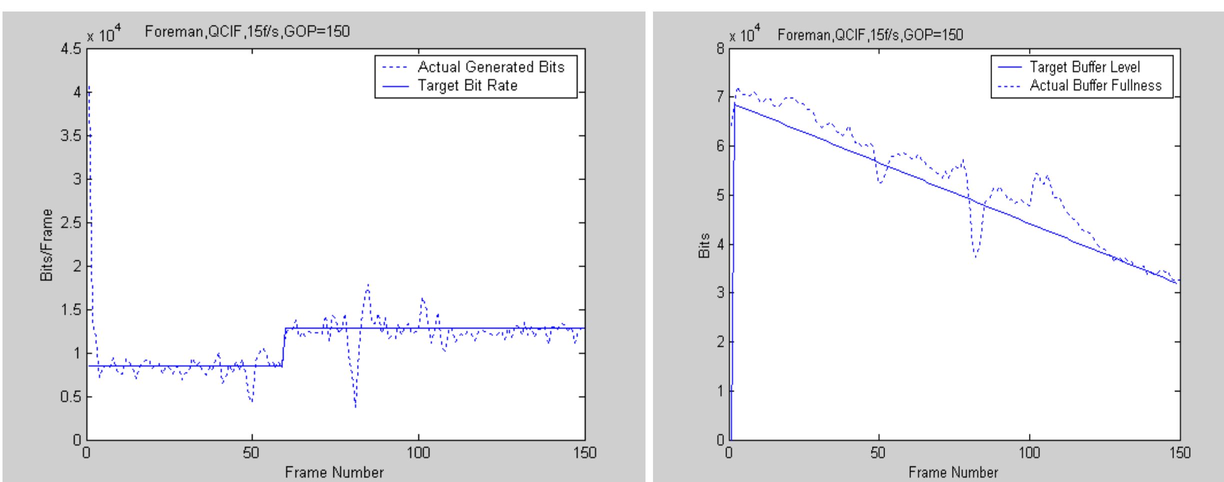

Figure 1 Experimental results for Foreman Under VBR

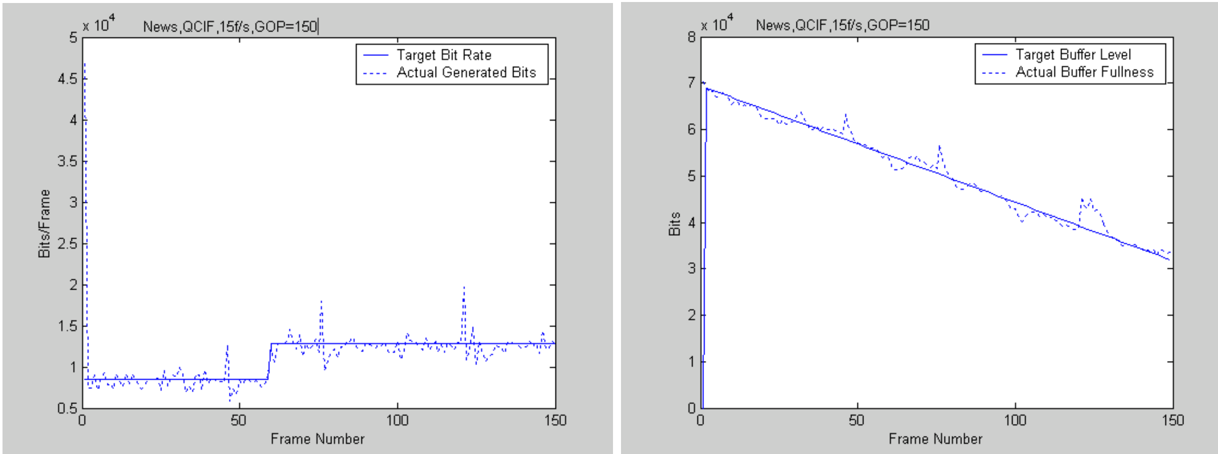

Figure 2 Experimental results for News Under VBR

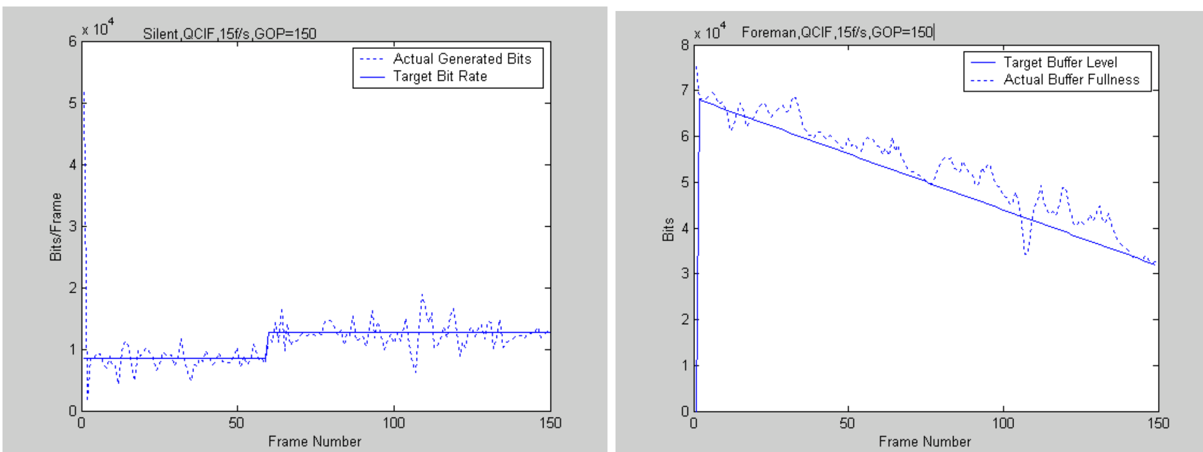

Figure 3 Experimental results for Silent Under VBR

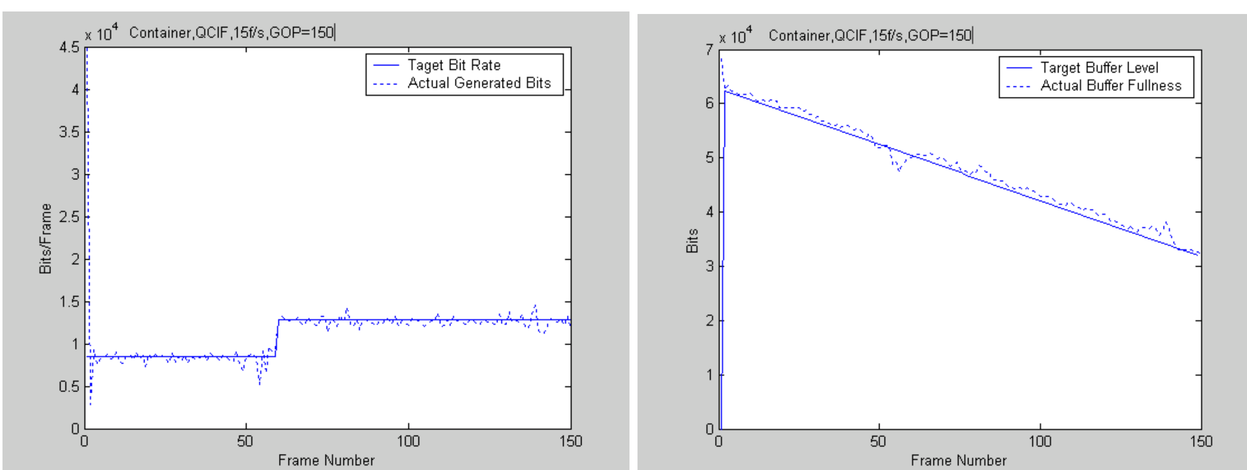

Figure 4 Experimental results for Container Under VBR

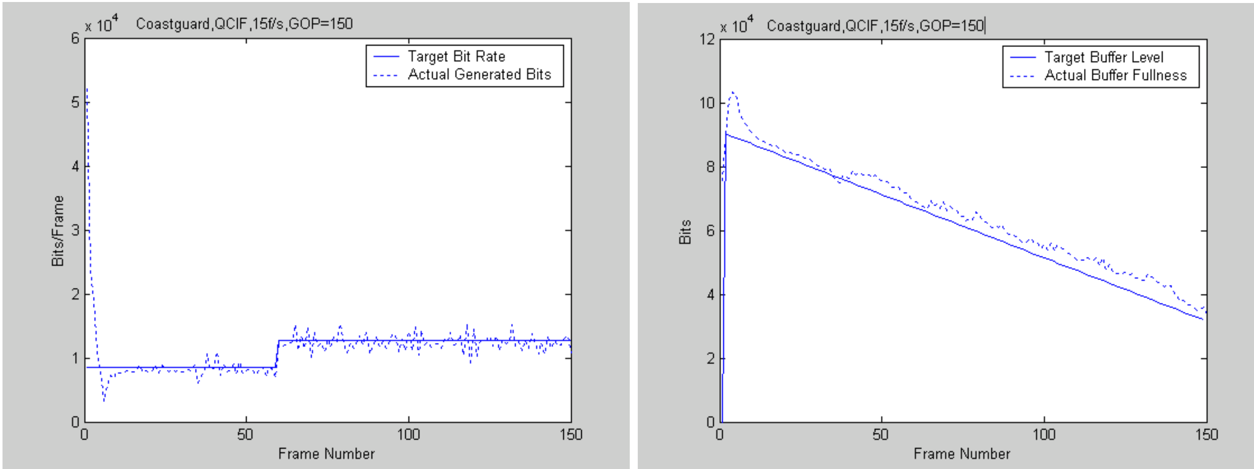

Figure 5 Experimental results for Coastguard Under VBR

Sequence	Y(dB)	U(dB)	V(dB)	Bandwidth(kb/s)
Foreman	39.08	42.32	43.30	166.89
News	43.63	45.56	46.00	166.96
Silent	42.78	44.44	44.96	166.87
Container	43.52	46.74	46.94	166.79
Coastguard	34.93	43.29	44.81	167.01

Table 2 Experimental Results for sequences with QCIF size under VBR

Test sequences: Paris, Mobile, Tempete and Goldfish; Format: CIF(4:2:0); Input frame rate is 30 f/s, encoded frame rate is 15f/s; QP for the first I picture is 26; Bandwidth: 512000 bits/s ($1 \le j \le 60$), 768000 bits/s $(61 \le j \le 150)$.

The experimental results for the sequences are given in the following Figures 6-9 and Table 3. It is shown that the actual generated bits are closed to their target bit rate and the actual buffer is kept close to its target buffer level. Moreover, the buffer is neither underflow nor overflow.

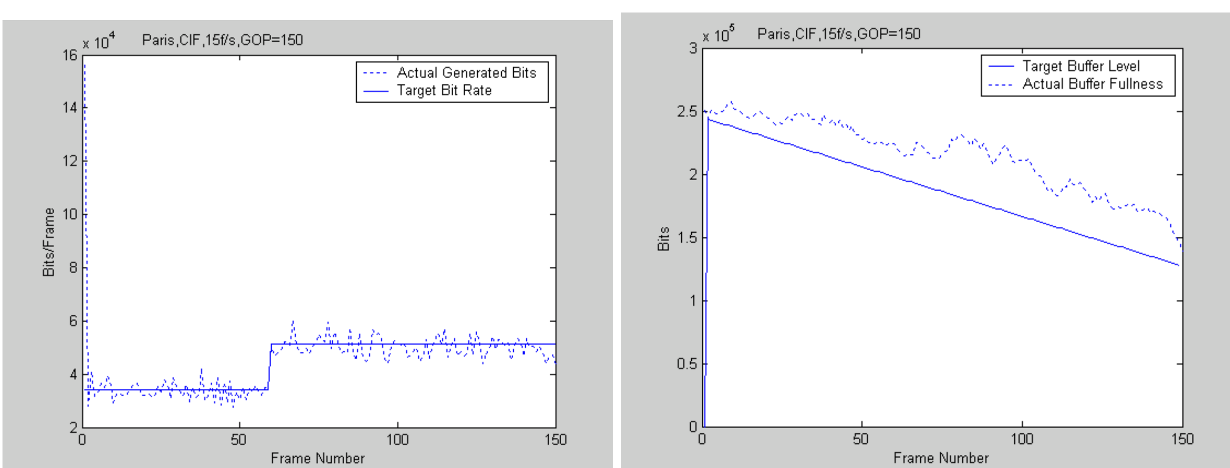

Figure 6 Experimental results for Paris Under VBR

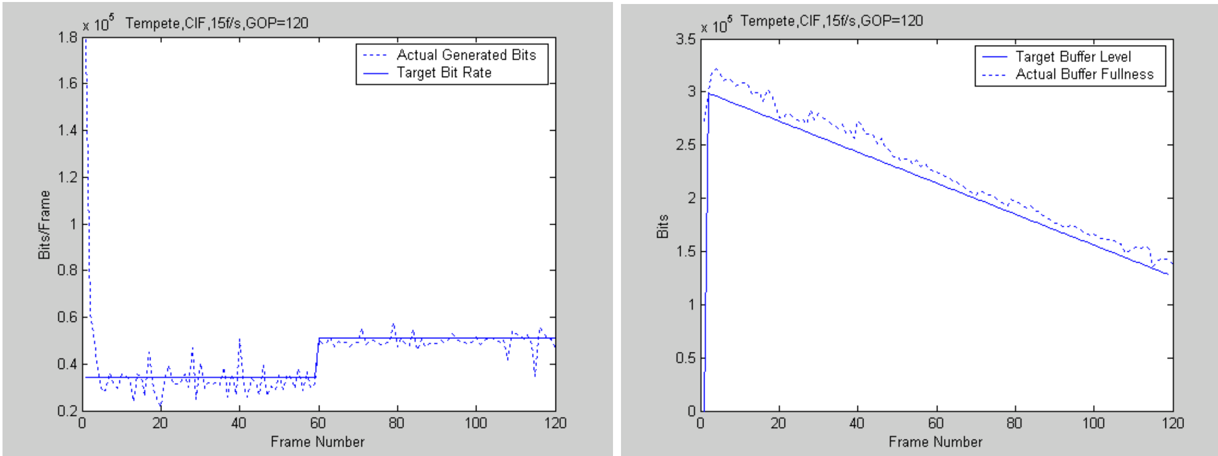

Figure 7 Experimental results for Tempete under VBR

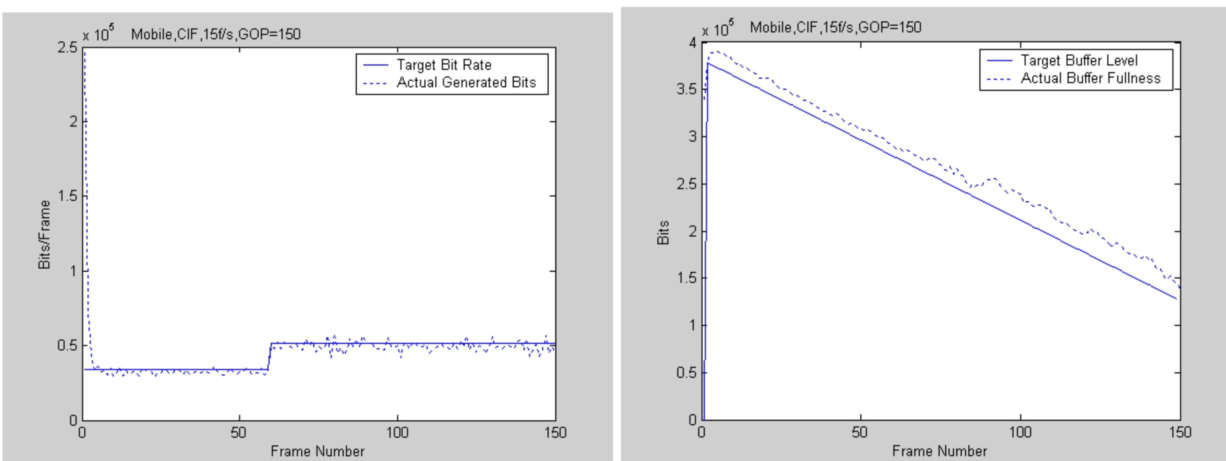

Figure 8 Experimental results for Mobile under VBR

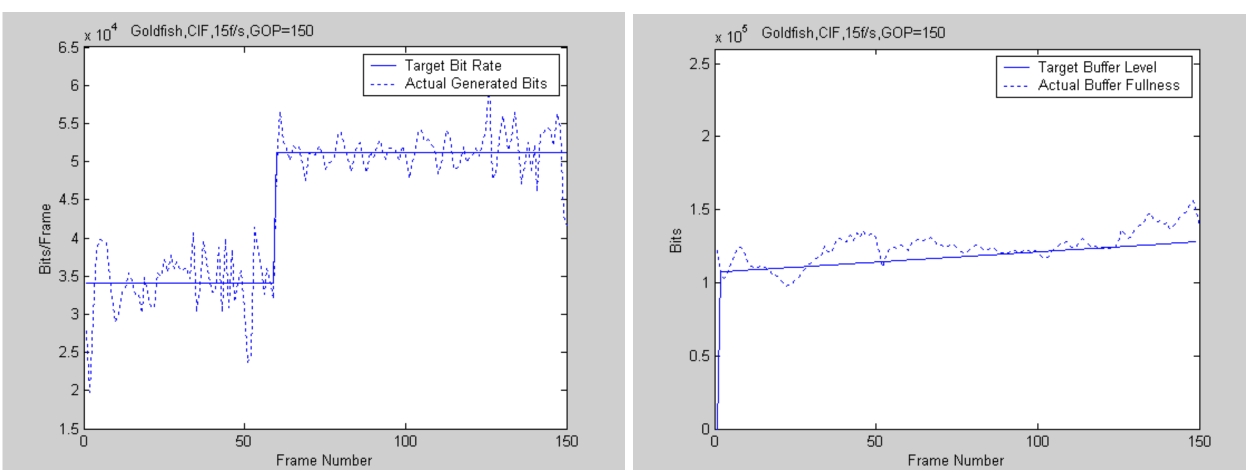

Figure 9 Experimental results for Goldfish under VBR

Sequence	Y(dB)	U(dB)	V(dB)	Bandwidth(kb/s)

Paris	39.70	42.15	42.31	668.35
Tempete	34.07	37.11	38.84	643.31
Mobile	31.94	34.85	34.64	668.31
Goldfish	40.59	43.46	43.46	668.36

Table 3 Experimental results for sequences with CIF size under VBR

Group 2 Constant bit rate (CBR)

The test conditions and test sequences are given in Tables 4 and 5, respectively. The bit rates are generated by coding the test sequences with fixed quantization parameters 28,32,36,40 and they are the target bit rates for an encoder with our rate control scheme. When the frame type is IPPP, the initial quantization parameters of our scheme are 24,28,32, and 36 respectively. When the frame type is IPBBP, the initial quantization parameters are 26,30,34, and 38 respectively.

MV resolution	1/4 pel
Hadamard	ON
RD optimization	ON
Search Range	$\pm$32(QCIF,CIF), ± 64 (HDTV)
Restrict Search Range	2
Reference Frames	1
Symbol Mode	CABAC
GOP structure	IBBPBB or IPPP
IntraPeriod	10 or 0

Table 4 Test Conditions

The experimental results are given in Tables 6-9. It can be shown from Tables 6-9 that the PSNR is improved by up to 1.02dB by using our scheme. The average PSNR of all testing sequences is improved by 0.32dB.

Test sequence	Size	Frame rate	Frames to be encoded	Frame Type	QP range	Search range	GOP length	Number B frame	Skip

Silent	QCIF	15	150	IPPP	28-40	32	0	0	1
Foreman	QCIF	10	100	IPPP	28-40	32	0	0	2
News	QCIF	10	100	IPPP	28-40	32	0	0	2
Container	QCIF	10	100	IPPP	28-40	32	0	0	2
Paris	CIF	15	150	IPPP	28-40	32	0	0	1
Mobile	CIF	30	300	IPPP	28-40	32	0	0	0
Tempete	CIF	30	240	IPPP	28-40	32	0	0	0
Silent	QCIF	15	50	IPBBP	28-40	32	10	2	5
Foreman	QCIF	15	50	IPBBP	28-40	32	10	2	5
News	QCIF	15	50	IPBBP	28-40	32	10	2	5
Container	QCIF	15	50	IPBBP	28-40	32	10	2	5
Coastguard	QCIF	30	100	IPBBP	28-40	32	10	2	2
Paris	CIF	15	50	IPBBP	28-40	32	10	2	5
Mobile	CIF	30	100	IPBBP	28-40	32	10	2	2
Goldfish	CIF	30	100	IPBBP	28-40	32	10	2	2
Bike	CIF	30	100	IPBBP	28-40	32	10	2	2
Stefan	CIF	30	100	IPBBP	28-40	32	10	2	2
Tempete	CIF	30	80	IPBBP	28-40	32	10	2	2
Bus	CIF	30	50	IPBBP	28-40	32	10	2	2
Harbour	HDTV	60	200	IPBBP	28-40	64	10	2	2
Spincalendar	HDTV	60	180	IPBBP	28-40	64	10	2	2
Night	HDTV	60	150	IPBBP	28-40	64	10	2	2
City	HDTV	60	300	IPBBP	28-40	64	10	2	2
Crew	HDTV	60	200	IPBBP	28-40	64	10	2	2

Table 5 Testing sequences and the configure file.

Sequence	Fixed Quantization Parameter				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y,dB)
Silent (IPP)	35.67	38.51	39.48	58.38	36.68	40.09	40.93	58.43	1.01
Foreman(IPP)	35.79	40.19	40.92	71.11	35.77	40.30	40.95	71.18	-0.02
News(IPP)	36.63	39.92	40.29	45.02	37.07	40.76	41.30	45.11	0.44
Container(IPP)	35.92	40.77	40.44	24.36	36.25	41.66	41.61	24.36	0.33
Paris(IPP)	35.48	38.81	38.82	313.79	35.80	39.54	39.54	314.29	0.32
Mobile(IPP)	33.70	35.56	35.41	1670.87	33.74	35.78	35.64	1671.62	0.04
Tempete(IPP)	34.63	37.02	38.67	1237.85	34.57	37.38	39.03	1238.78	-0.06
News(IPBBP)	37.08	40.30	40.75	60.36	37.72	41.39	41.92	60.49	0.64
Foreman(IPBBP)	36.03	40.39	41.22	88.71	36.17	40.81	41.60	88.98	0.14
Container(IPBBP)	36.43	41.21	41.03	30.38	36.85	42.25	42.02	30.42	0.42
Silent(IPBBP)	35.99	38.85	39.82	63.77	36.81	40.09	41.02	64.02	0.82
Coastguard(IPBBP)	34.32	42.53	44.60	173.06	34.66	43.53	45.38	173.38	0.34
Paris(IPBBP)	35.77	39.10	39.24	341.51	36.61	40.30	40.52	347.41	0.84
Mobile(IPBBP)	33.77	35.85	35.73	1325.66	34.30	36.82	36.65	1329.20	0.53
Goldish(IPBBP)	39.03	42.45	42.52	802.19	39.24	43.22	43.17	808.82	0.21
Bike(IPBBP)	36.93	43.15	49.09	963.76	37.32	44.35	49.52	967.30	0.39
Stefan(IPBBP)	35.29	37.94	38.06	1241.99	35.36	38.41	38.58	1243.12	0.07
Tempete(IPBBP)	34.65	37.27	39.06	1046.94	34.95	38.14	39.84	1051.49	0.30
Bus(IPBBP)	34.77	40.38	42.18	1072.68	35.12	41.10	42.92	1080.17	0.35
Harbour(IPBBP)	35.74	42.60	44.57	10758.26	35.74	43.34	45.32	10770.79	0
Spincalendar(IPBB)	35.30	40.25	38.46	4985.21	35.42	40.52	38.76	4989.96	0.12
Night(IPBBP)	36.60	40.25	41.87	8082.84	36.82	40.72	42.51	8094.30	0.22
City(IPBBP)	36.14	43.24	43.73	4061.44	36.35	43.66	44.12	4063.82	0.21
Crew(IPBBP)	38.60	43.29	43.59	5448.14	38.48	43.30	43.73	5453.29	-0.12

Table 6 Comparison results for QP=28

Sequence	Fixed Quantization Parameter				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y, dB)
Silent (IPP)	32.74	36.96	38.26	34.11	33.76	38.14	39.13	34.16	1.02
Foreman(IPP)	32.97	39.05	39.46	42.68	33.03	38.98	39.48	42.74	0.06
News(IPP)	33.50	38.37	38.86	27.29	34.09	38.96	39.32	27.28	0.59
Container(IPP)	33.10	39.41	38.82	12.93	33.74	40.10	39.63	12.95	0.64
Paris(IPP)	32.32	37.05	37.16	181.28	32.81	37.51	37.66	181.55	0.49
Mobile(IPP)	30.17	33.70	33.45	831.05	30.22	33.67	33.42	831.63	0.05
Tempete(IPP)	31.38	35.54	37.44	600.10	31.39	35.69	37.56	600.70	0.01
News(IPBBP)	34.02	38.62	39.20	37.61	34.78	39.42	39.89	37.82	0.76
Foreman(IPBBP)	33.21	39.15	39.78	53.17	33.31	39.20	39.83	53.28	0.1
Container(IPBBP)	33.69	39.61	39.26	17.07	34.19	40.39	40.12	17.07	0.5
Silent(IPBBP)	33.08	37.05	38.58	37.55	33.57	37.73	38.97	37.69	0.49
Coastguard(IPBBP)	31.50	41.06	43.61	84.32	31.77	41.83	44.04	84.67	0.27
Paris(IPBBP)	32.70	37.24	37.49	199.80	33.45	38.04	38.27	202.14	0.75
Mobile(IPBBP)	30.46	34.09	33.84	646.49	30.98	34.63	34.31	649.35	0.52
Goldish(IPBBP)	36.10	40.80	40.67	494.64	36.35	41.22	41.69	498.02	0.25
Bike(IPBBP)	33.52	42.66	48.46	610.07	33.91	43.04	48.87	610.67	0.39
Stefan(IPBBP)	32.12	36.35	36.35	665.30	32.19	36.52	36.57	665.50	0.07
Tempete(IPBBP)	31.52	35.72	37.75	493.43	31.89	36.24	38.18	495.26	0.37
Bus(IPBBP)	31.75	39.24	40.86	592.09	32.07	39.67	41.42	596.03	0.32
Harbour(IPBBP)	33.20	41.43	43.37	5059.30	33.23	41.90	43.92	5068.21	0.03
Spincalendar(IPBB)	33.27	39.29	37.10	2459.85	33.50	39.54	37.41	2464.49	0.23
Night(IPBBP)	34.23	38.70	40.36	4125.58	34.56	39.02	40.84	4131.86	0.33
City(IPBBP)	33.75	42.16	42.62	1897.60	33.94	42.37	42.82	1899.57	0.19
Crew(IPBBP)	36.72	42.17	42.04	2868.39	36.62	42.15	42.02	2871.04	-0.1

Table 7 Comparison results for QP=32

Sequence	Fixed Quantization Parameter				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y, dB)
Silent (IPP)	30.25	35.35	36.94	19.66	31.14	36.53	37.86	19.69	0.89
Foreman(IPP)	30.41	37.78	37.91	26.22	30.46	37.91	38.21	26.24	0.05
News(IPP)	30.59	36.12	37.17	16.55	31.23	37.42	38.13	16.62	0.64
Container(IPP)	30.35	37.68	37.28	7.48	31.22	38.85	38.23	7.46	0.87
Paris(IPP)	29.39	35.15	35.38	101.18	29.99	35.94	36.19	101.31	0.60
Mobile(IPP)	27.02	31.80	31.48	388.73	26.93	31.94	31.61	389.18	-0.09
Tempete(IPP)	28.58	34.01	36.03	289.05	28.61	34.30	36.32	289.37	0.03
News(IPBBP)	31.08	36.39	37.36	22.84	31.78	37.55	38.37	23.03	0.7
Foreman(IPBBP)	30.53	37.82	37.92	31.98	30.69	38.11	38.37	32.19	0.16
Container(IPBBP)	31.06	37.63	37.62	10.32	31.46	38.53	38.09	10.43	0.4
Silent(IPBBP)	30.49	35.40	37.09	21.34	31.03	36.20	37.81	21.46	0.54
Coastguard(IPBBP)	29.05	40.34	42.51	41.89	29.28	40.51	43.10	42.10	0.23
Paris(IPBBP)	29.82	35.34	35.63	113.91	30.39	36.03	36.42	115.33	0.75
Mobile(IPBBP)	27.60	32.28	31.94	328.84	28.04	32.82	32.40	331.27	0.44
Goldish(IPBBP)	33.35	39.01	38.63	301.26	33.57	39.54	39.31	304.72	0.22
Bike(IPBBP)	30.40	42.14	47.93	379.66	30.97	42.14	48.26	379.98	0.57
Stefan(IPBBP)	29.28	34.73	34.57	380.92	29.43	35.21	35.12	380.34	0.15
Tempete(IPBBP)	28.85	34.14	36.37	243.98	29.23	34.61	36.84	244.89	0.38
Bus(IPBBP)	28.99	38.03	39.30	325.99	29.25	38.44	39.96	328.42	0.26
Harbour(IPBBP)	30.73	40.10	41.78	2530.71	30.82	40.65	42.50	2534.31	0.09
Spincalendar(IPBB)	31.13	38.19	35.67	1418.07	31.21	38.48	36.06	1424.49	0.08
Night(IPBBP)	31.91	36.97	38.69	2246.05	32.23	37.39	39.30	2250.05	0.32
City(IPBBP)	31.44	40.95	41.33	1048.23	31.45	41.25	41.60	1050.49	0.01
Crew(IPBBP)	34.77	40.66	40.13	1579.81	34.65	40.82	40.27	1581.19	-0.12

Table 8 Comparison results for QP=36

Sequence	Fixed Quantization Parameter Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Our Scheme Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Improvement (Y, dB)
Silent (IPP)	27.89	34.54	36.20	11.46	28.82	35.16	36.87	11.49	0.93
Foreman(IPP)	27.93	36.86	36.87	16.58	28.09	36.96	37.00	16.61	0.16
News(IPP)	28.00	34.96	36.28	10.18	28.77	35.76	36.72	10.17	0.77
Container(IPP)	27.90	36.97	36.53	4.70	28.79	37.59	36.99	4.72	0.89
Paris(IPP)	26.74	33.66	34.38	58.11	27.43	34.49	34.81	58.26	0.69
Mobile(IPP)	24.32	30.63	30.21	205.19	24.33	30.72	30.41	205.52	0.01
Tempete(IPP)	26.17	33.05	35.21	155.38	26.29	33.28	35.45	155.53	0.12
News(IPBBP)	28.35	35.07	36.27	13.92	28.88	35.72	36.72	13.99	0.53
Foreman(IPBBP)	27.92	36.85	36.81	19.23	27.74	36.77	36.60	19.29	-0.18
Container(IPBBP)	28.71	36.73	36.59	6.67	28.78	36.87	36.67	6.79	0.07
Silent(IPBBP)	28.07	34.47	36.29	12.13	28.48	34.81	36.57	12.21	0.41
Coastguard(IPBBP)	26.85	39.42	41.35	22.20	27.04	39.18	41.72	22.39	0.19
Paris(IPBBP)	27.10	33.80	34.34	64.70	27.68	34.32	34.88	65.61	0.58
Mobile(IPBBP)	25.04	31.04	30.58	184.80	25.40	31.42	30.88	186.34	0.36
Goldish(IPBBP)	30.79	37.79	37.32	185.75	30.95	38.10	37.83	186.93	0.18
Bike(IPBBP)	27.53	41.74	47.88	232.64	28.17	42.06	47.89	233.96	0.64
Stefan(IPBBP)	26.52	33.66	33.42	223.64	26.88	34.03	33.82	223.72	0.36
Tempete(IPBBP)	26.40	33.02	35.35	129.47	26.78	33.31	35.71	130.08	0.38
Bus(IPBBP)	26.55	37.22	38.40	182.55	26.72	37.48	38.78	184.03	0.17
Harbour(IPBBP)	28.31	39.14	40.39	1254.99	28.49	39.44	41.40	1256.42	0.18
Spincalendar(IPBB)	28.84	37.33	34.76	907.69	28.77	37.51	35.05	912.12	-0.07
Night(IPBBP)	29.59	35.65	37.51	1269.25	29.91	35.90	37.92	1272.26	0.32
City(IPBBP)	29.13	40.11	40.33	647.75	28.90	40.33	40.58	649.81	-0.23
Crew(IPBBP)	32.78	39.35	38.57	903.05	32.69	39.40	38.62	903.77	-0.09

Table 9 Comparison results for QP=40

7. Conclusions.

An adaptive basic unit layer rate control scheme is proposed for JVT. The basic unit can be a macroblock, a slice, a field, or a frame. The linear model is used to predict the MAD of current basic unit in the current frame by that of basic unit in the same position of previous frame, and the chicken and egg dilemma existing in the rate control of JVT is thus avoided. Our scheme is directly based on a fluid-flow traffic model, the virtual buffer is not underflowed nor overflowed, and is thus conformed to HRD. Moreover, it is applicable in both the VBR case and the CBR case. It is applicable regardless of choice of basic unit.

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Appendix Comparison between Our scheme and F086

Sequence	F086				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y,dB)
Silent (IPP)	36.09	39.27	40.17	58.36	36.68	40.09	40.93	58.43	**0.59**
Foreman(IPP)	35.55	40.22	40.91	71.01	35.77	40.30	40.95	71.18	0.22
News(IPP)	37.04	40.58	41.19	45.02	37.07	40.76	41.30	45.11	0.03
Container(IPP)	35.70	40.60	40.30	24.36	36.25	41.66	41.61	24.36	**0.55**
Paris(IPP)	35.01	38.31	38.42	313.98	35.80	39.54	39.54	314.29	**0.79**
Mobile(IPP)	33.70	35.56	35.41	1670.87	33.74	35.78	35.64	1671.62	0.03
Tempete(IPP)	34.65	37.11	38.76	1237.75	34.57	37.38	39.03	1238.78	-0.08
News(IPBBP)	37.11	40.76	41.42	60.09	37.72	41.39	41.92	60.49	**0.61**
Foreman(IPBBP)	35.68	40.75	41.37	88.34	36.17	40.81	41.60	88.98	0.39
Container(IPBBP)	35.67	40.84	40.68	30.15	36.85	42.25	42.02	30.42	**1.18**
Silent(IPBBP)	36.51	39.87	40.82	63.37	36.81	40.09	41.02	64.02	0.30
Coastguard(IPBBP)	34.32	42.53	44.60	173.06	34.66	43.53	45.38	173.38	0.34
Paris(IPBBP)	36.15	39.57	39.76	341.65	36.61	40.30	40.52	347.41	0.46
Mobile(IPBBP)	33.77	35.85	35.73	1325.66	34.30	36.82	36.65	1329.20	**0.53**
Goldish(IPBBP)	39.25	43.20	43.18	802.67	39.24	43.22	43.17	808.82	-0.01
Bike(IPBBP)	37.54	43.81	49.30	963.71	37.32	44.35	49.52	967.30	-0.22
Stefan(IPBBP)	35.55	38.53	38.69	1242.59	35.36	38.41	38.58	1243.12	-0.19
Tempete(IPBBP)	34.96	37.79	39.49	1046.82	34.95	38.14	39.84	1051.49	-0.01
Bus(IPBBP)	35.09	40.81	42.65	1072.14	35.12	41.10	42.92	1080.17	0.03
Harbour(IPBBP)	NA	NA	NA	NA	35.74	43.34	45.32	10770.79	NA
Spincalendar(IPBB)	NA	NA	NA	NA	35.42	40.52	38.76	4989.96	NA
Night(IPBBP)	NA	NA	NA	NA	36.82	40.72	42.51	8094.30	NA
City(IPBBP)	NA	NA	NA	NA	36.35	43.66	44.12	4063.82	NA
Crew(IPBBP)	NA	NA	NA	NA	38.48	43.30	43.73	5453.29	NA

Compare results for QP=28

Sequence	F086				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y, dB)
Silent (IPP)	32.76	36.96	38.34	34.11	33.76	38.14	39.13	34.16	**1.00**
Foreman(IPP)	32.75	38.88	39.38	42.62	33.03	38.98	39.48	42.74	0.28
News(IPP)	33.98	38.97	39.46	27.30	34.09	38.96	39.32	27.28	0.11
Container(IPP)	32.78	39.29	38.64	12.92	33.74	40.10	39.63	12.95	**0.96**
Paris(IPP)	31.68	36.10	36.55	181.39	32.81	37.51	37.66	181.55	**1.13**
Mobile(IPP)	30.23	33.64	33.40	831.00	30.22	33.67	33.42	831.63	-0.01
Tempete(IPP)	31.40	35.48	37.39	600.05	31.39	35.69	37.56	600.70	-0.01
News(IPBBP)	33.42	38.26	39.18	37.32	34.78	39.42	39.89	37.82	**1.36**
Foreman(IPBBP)	32.63	39.15	39.59	53.05	33.31	39.20	39.83	53.28	**0.68**
Container(IPBBP)	33.05	39.24	38.94	16.91	34.19	40.39	40.12	17.07	**1.14**
Silent(IPBBP)	33.08	37.38	38.68	37.27	33.57	37.73	38.97	37.69	0.49
Coastguard(IPBBP)	31.50	41.54	43.90	84.62	31.77	41.83	44.04	84.67	0.27
Paris(IPBBP)	32.67	37.10	37.36	199.86	33.45	38.04	38.27	202.14	**0.78**
Mobile(IPBBP)	30.75	34.40	34.13	646.63	30.98	34.63	34.31	649.35	0.23
Goldish(IPBBP)	36.28	41.20	41.09	494.71	36.35	41.22	41.69	498.02	0.07
Bike(IPBBP)	34.16	42.94	48.96	609.86	33.91	43.04	48.87	610.67	-0.25
Stefan(IPBBP)	32.39	36.53	36.56	662.24	32.19	36.52	36.57	665.50	-0.20
Tempete(IPBBP)	31.61	35.79	37.79	493.68	31.89	36.24	38.18	495.26	0.28
Bus(IPBBP)	31.85	39.29	40.95	591.79	32.07	39.67	41.42	596.03	0.22
Harbour(IPBBP)	NA	NA	NA	NA	33.23	41.90	43.92	5068.21	NA
Spincalendar(IPBB)	NA	NA	NA	NA	33.50	39.54	37.41	2464.49	NA
Night(IPBBP)	NA	NA	NA	NA	34.56	39.02	40.84	4131.86	NA
City(IPBBP)	NA	NA	NA	NA	33.94	42.37	42.82	1899.57	NA
Crew(IPBBP)	NA	NA	NA	NA	36.62	42.15	42.02	2871.04	NA

Compare results for QP=32

Sequence	F086				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y, dB)
Silent (IPP)	30.22	35.71	37.19	19.67	31.14	36.53	37.86	19.69	**0.92**
Foreman(IPP)	30.14	37.74	38.06	26.20	30.46	37.91	38.21	26.24	0.32
News(IPP)	30.64	36.69	37.36	16.57	31.22	38.85	38.23	16.62	**0.58**
Container(IPP)	29.83	37.78	37.39	7.47	31.22	38.85	38.23	7.46	**1.39**
Paris(IPP)	28.53	34.51	35.13	101.21	29.99	35.94	36.19	101.31	**1.46**
Mobile(IPP)	26.92	31.91	31.56	388.70	26.93	31.94	31.61	389.18	0.01
Tempete(IPP)	28.55	34.10	36.14	289.05	28.61	34.30	36.32	289.37	0.06
News(IPBBP)	30.45	36.71	37.81	22.70	31.78	37.55	38.37	23.03	**1.33**
Foreman(IPBBP)	30.50	38.06	38.45	31.77	30.69	38.11	38.37	32.19	0.19
Container(IPBBP)	30.84	37.98	37.64	10.81	31.46	38.53	38.09	10.43	**0.62**
Silent(IPBBP)	30.53	35.84	37.40	21.09	31.03	36.20	37.81	21.46	**0.50**
Coastguard(IPBBP)	28.80	40.15	42.44	41.67	29.28	40.51	43.10	42.10	**0.48**
Paris(IPBBP)	29.48	35.12	35.52	113.91	30.39	36.03	36.42	115.33	**0.91**
Mobile(IPBBP)	27.51	32.45	32.08	329.22	28.04	32.82	32.40	331.27	**0.53**
Goldish(IPBBP)	33.35	39.01	38.63	301.26	33.57	39.54	39.31	304.72	0.22
Bike(IPBBP)	30.96	42.35	48.14	379.52	30.97	42.14	48.26	379.98	0.01
Stefan(IPBBP)	29.50	35.09	34.98	381.35	29.43	35.21	35.12	380.34	-0.07
Tempete(IPBBP)	28.74	34.23	36.45	243.96	29.23	34.61	36.84	244.89	0.49
Bus(IPBBP)	28.98	38.26	39.55	325.76	29.25	38.44	39.96	328.42	0.27
Harbour(IPBBP)	NA	NA	NA	NA	30.82	40.65	42.50	2534.31	NA
Spincalendar(IPBB)	NA	NA	NA	NA	31.21	38.48	36.06	1424.49	NA
Night(IPBBP)	NA	NA	NA	NA	32.23	37.39	39.30	2250.05	NA
City(IPBBP)	NA	NA	NA	NA	31.45	41.25	41.60	1050.49	NA
Crew(IPBBP)	NA	NA	NA	NA	34.65	40.82	40.27	1581.19	NA

Comparison results for QP=36

Sequence	F086				Our Scheme				Improvement
	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	Y(dB)	U(dB)	V(dB)	Bandwidth (kb/s)	(Y, dB)
Silent (IPP)	28.08	34.84	36.33	11.47	28.82	35.16	36.87	11.49	**0.74**
Foreman(IPP)	27.67	36.76	36.76	16.57	28.09	36.96	37.00	16.61	0.42
News(IPP)	28.06	35.46	36.51	10.19	28.77	35.76	36.72	10.17	**0.71**
Container(IPP)	27.57	36.80	36.37	4.69	28.79	37.59	36.99	4.72	**1.22**
Paris(IPP)	25.70	33.36	34.16	58.17	27.43	34.49	34.81	58.26	**1.73**
Mobile(IPP)	24.17	30.72	30.29	205.18	24.33	30.72	30.31	205.52	0.16
Tempete(IPP)	26.14	33.19	35.31	155.39	26.29	33.28	35.45	155.53	0.15
News(IPBBP)	27.81	35.41	36.47	13.79	28.88	35.72	36.72	13.99	**1.07**
Foreman(IPBBP)	27.66	36.85	36.93	19.13	27.74	36.77	36.60	19.29	0.08
Container(IPBBP)	27.36	36.58	36.13	6.77	28.78	36.87	36.67	6.79	**1.42**
Silent(IPBBP)	28.02	34.53	36.39	12.13	28.48	34.81	36.57	12.21	0.46
Coastguard(IPBBP)	26.85	39.42	41.35	22.20	27.04	39.18	41.72	22.39	0.19
Paris(IPBBP)	26.97	33.83	34.39	64.62	27.68	34.32	34.88	65.61	**0.71**
Mobile(IPBBP)	24.23	30.98	30.39	185.07	25.40	31.42	30.88	186.34	**1.17**
Goldish(IPBBP)	30.79	37.79	37.32	185.75	30.95	38.10	37.83	186.93	0.18
Bike(IPBBP)	28.08	41.88	47.65	232.52	28.17	42.06	47.89	233.96	0.09
Stefan(IPBBP)	26.64	33.92	33.70	223.92	26.88	34.03	33.82	223.72	0.24
Tempete(IPBBP)	25.91	32.93	35.24	129.80	26.78	33.31	35.71	130.08	**0.87**
Bus(IPBBP)	26.53	37.37	38.51	182.50	26.72	37.48	38.78	184.03	0.19
Harbour(IPBBP)	NA	NA	NA	NA	28.49	39.44	41.40	1256.42	NA
Spincalendar(IPBB)	NA	NA	NA	NA	28.77	37.51	35.05	912.12	NA
Night(IPBBP)	NA	NA	NA	NA	29.91	35.90	37.92	1272.26	NA
City(IPBBP)	28.05	39.93	40.25	647.87	28.90	40.33	40.58	649.81	**0.85**
Crew(IPBBP)	NA	NA	NA	NA	32.69	39.40	38.62	903.77	NA

Comparison results for QP=40

(Append for Proposal Documents)

JVT Patent Disclosure Form

International Telecommunication Union Telecommunication Standardization Sector	International Organization for Standardization	International Electrotechnical Commission

Joint Video Coding Experts Group - *Patent Disclosure Form*

(Typically one per contribution and one per Standard | Recommendation)

Please send to:

JVT Rapporteur Gary Sullivan, Microsoft Corp., One Microsoft Way, Bldg. 9, Redmond WA 98052-6399, USA
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