On video coding algorithms with application level QoS guarantees

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Abstract

To transfer video streams with the application level QoS (Quality of Service) guarantees on the end-to-end transfer delay and the video quality, the coding algorithm and parameters should be determined appropriately considering network conditions. In this paper, by comparing four coding algorithms specified in MPEG-2 through simulation experiments, we show that intra-slice coding algorithms outperform the others in the video transfer over the statically allocated bandwidth. We further introduce an easy and straightforward modification to the VBR intra-slice coding algorithm. The proposed algorithm is effective to achieve smaller end-to-end delay by applying the doubled quantizer scale to the first picture.

Key words: QoS, MPEG-2, intra-slice coding, bandwidth allocation

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1 Introduction

In these days, with increasing demands on distributed multimedia applications, many researches have been devoted to the development of effective video transfer mechanism. To achieve the effective and impressive video presentation in distributed multimedia applications, the video transfer must be provided

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with consideration on the application level QoS (Quality of Service) requirements in terms of the video quality and the end-to-end delay [1,2].

The network level QoS such as loss ratio, delay and delay jitter can be guaranteed by employing the bandwidth reservation based network, e.g., ATM (Asynchronous Transfer Mode) [3] and RSVP (Resource ReSerVation Protocol) [4]. By allocating the sufficient bandwidth to a connection, those network level QoS requirements are deterministically guaranteed and the effective resource utilization can also be achieved [5]. When the video stream is injected into the statically allocated bandwidth, we should take into account the bursty nature of coded video traffic. If the network is not congested and there is much available bandwidth, one may reserve bandwidth larger than the instantaneous peak rate of the video traffic and, as a result, low-delay and loss-free video transmission can be accomplished. However, in an actual situation, bandwidth one can occupy should be limited because the network resource is shared among connections, and the network system would employ some bandwidth management mechanisms in order to prevent user's monopoly. Further, estimation of required bandwidth is difficult in interactive video applications such as the video conferencing where the video coding is performed in a real-time fashion. In such a case that the estimation fails and the reserved bandwidth is smaller than the actual peak rate, the video traffic should be smoothed by an appropriate UPC (Usage Parameter Control) mechanism such as leaky bucket [6]. As a result, the video traffic can be transferred over the insufficient bandwidth without loss as far as the smoothing buffer is large enough. However, the extra buffering delay introduced by the smoothing control affects the interactivity of the real-time video application.

To satisfy the end-to-end delay requirement of, e.g., a few hundreds milliseconds, we should employ the application-level rate control method to regulate the video traffic according to the allocated bandwidth. In MPEG-2 standard [7], which is a widely used coding algorithm, the CBR (Constant Bit Rate) coding algorithm is specified for rate adjusting. In the CBR coding, the degree of quantization is dynamically controlled according to the buffer occupancy level, and the traffic rate averaged over several pictures becomes close to the allocated bandwidth [8]. Consequently, the buffering delay decreases and the video transfer with relatively small end-to-end delay can be achieved. However, as a result of quantization control, the perceived video quality becomes unstable [9]. On the other hand, the VBR (Variable Bit Rate) coding algorithm which employs the static quantization parameter produces video streams of relatively constant quality, but the resultant traffic has a highly bursty nature. Both the CBR and VBR coding algorithms employ a combination of three types of picture compression algorithms, i.e., I (Intra coded), P (Predictive coded) and B (Bi-directionally predictive coded) pictures. The video stream consists of the repetition of specific picture sequence, called GoP (Group of Pictures), and the high compression ratio is achieved in those two coding algorithms. However, the traffic rate fluctuates picture by picture dependent on the picture type.

The intra-slice coding is another coding algorithm which accomplishes “low delay mode” specified in the standard. In contrast with the other two coding algorithms, the intra-slice coding does not employ the GoP structure. As a result, the video quality is expected to be kept stable and the traffic rate fluctuates little throughout the whole video sequence. However, the picture size drastically changes when a scene change occurs as will be shown later. The intra-slice coding can also employ either the fixed quantizer scale and the quantization control as in GoP based coding.

The MPEG-2 coding algorithm is widely used for TV broadcasting, communication and digital storage media. The standard only specifies the structure of coded bitstream and the decoding process. Thus, the video server or the sending end station can freely choose the coding algorithm among CBR, VBR and intra-slice and parameters considering the application level QoS requirements such as the video quality and the end-to-end delay. However, there has been little investigation into determination of the coding algorithm and parameters appropriate for the required QoS. For example, in [10], we have investigated the relationship among the perceived video quality, the required bandwidth and the coding parameters, but we considered the VBR coding algorithm.

In this paper, through comparison among the VBR, CBR, intra-slice coding algorithms using the actual video data, we investigate the most effective coding algorithm and parameter settings appropriate for satisfying the application level QoS requirements on the video quality and the end-to-end delay. The organization of the paper is as follows. In Section 2, we briefly introduce four MPEG-2 coding algorithms, i.e. CBR, VBR, CBR intra-slice and VBR intra-slice. In Section 3, we compare four coding algorithms in terms of traffic characteristics, video quality and end-to-end delay. Further in Section 4, based on the comparison in Section 3, we investigate which coding algorithm can accomplish the low delay and high quality video transfer over the allocated bandwidth by considering the application level QoS requirements. We also introduce the “MQ intra-slice coding algorithm” which can be easily implemented based on the VBR intra-slice coding. Finally, Section 5 concludes the paper and shows some future works.

2 MPEG-2 coding algorithm

In this section, we briefly introduce four MPEG-2 coding algorithms, CBR, VBR, CBR intra-slice and VBR intra-slice.

The MPEG-2 coding algorithm achieves the high compression ratio by combining three types of pictures, i.e., I (Intra coded), P (Predictive coded) and B (Bi-directionally predictive coded) pictures. The I picture is coded using information only from itself. The resultant picture size is the largest among three types of pictures, but the degradation in picture quality is the smallest. The video stream must contain at least one I picture. By inserting one or more I pictures in a video sequence, the video playout can recover from the data loss while increasing the instantaneous traffic. The P picture is a picture coded using motion compensated prediction from a preceding I or P picture. To decode and display a P picture, the preceding I or P picture must be decoded successfully. The picture size is the second largest and the picture quality is the second highest among three. Finally, the B picture is coded using motion compensated prediction from both a preceding and a following I or P pictures. The compression ratio in the B picture is the highest, but the picture quality is the lowest. The picture reordering is necessary when introducing the B pictures because a following reference picture must be coded and decoded prior to the B picture, which incurs the extra delays.

A GoP (Group of Pictures) structure is optional in the MPEG-2 standard, but still widely used to enable a random access and achieve an error resilience. The GoP consists of one I picture and a number of P and B pictures. The size of GoP, i.e., the number of pictures in a GoP, is specified by the parameter N, and the distance between I and P pictures is specified by the parameter M. An example of the GoP ($N = 15$ and $M = 3$) is shown in Fig.1. Choices of N and M affect the perceived video quality and the traffic characteristics.

Each picture consists of a number of slices, and a slice is made up from macroblocks of 16x16 pixels large. The DCT (Discrete Cosine Transform) is performed on the macroblock basis and each DCT coefficient is further quantized with the quantizer scale. In the VBR coding algorithm, the quantizer scale is identical for all macroblocks in the video stream. As a result, the coded video stream has relatively constant quality, but generates a highly bursty traffic. On the contrary, the CBR coding algorithm employs the rate control method which adjusts the quantizer scale according to the allocated bandwidth and the buffer occupancy level. More specifically, the target GoP size is first determined from the allocated bandwidth in the CBR coding. Then, the target picture size is specified for each picture in a GoP. In coding each picture, the quantizer scale is dynamically changed on the macroblock basis to fit the coded picture size to the allocated bits. The resultant traffic rate averaged over GoP becomes close to the allocated bandwidth. However, even if the rate control is employed, the picture-by-picture rate fluctuation is unavoidable. In addition, the picture quality fluctuates within a picture and between pictures because of the quantization control.

2.2 Intra-slice coding algorithm

In contrast with the other two, the intra-slice coding algorithm does not employ the GoP structure. Instead, only the first picture of the video stream is intra-coded (I picture) and the others are predictively coded (P picture). One or more slices in each predictively coded picture are intra-coded and called *intra-slice*. By rotating positions of intra-slice picture by picture, the whole picture is regularly refreshed and the application can recover from the quality degradation caused by data loss (see Fig.2). The refresh cycle can be regulated according to the desirable error resilience by the number of intra-slice in a picture.

By eliminating the GoP structure, the intra-slice coding achieves the small fluctuation in both traffic and picture quality. Examples are shown in Figs.3 and 4 for the traffic rate in Mbps and the video quality in terms of SNR (Signal to Noise Ratio), respectively. The average rate is about 5 Mbps in all coding algorithms. The intra-slice coding can employ either the fixed quantizer scale (called "VBR intra-slice coding algorithm" in this paper) and the quantization control ("CBR intra-slice") as in GoP based coding. From Fig. 3, we can observe the picture-by-picture rate fluctuation in both CBR and VBR coding algorithms. In the case of the CBR coding, the picture quality also fluctuates because of the quantization control as shown in Fig. 4. On the other hand, with both of CBR and VBR intra-slice coding algorithms, more stable characteristics are obtained. However, we can also observe instantaneous and drastic rate increases in the intra-slice coded video traffic when scene changes occur (see Fig. 5). Although all the pictures except the first one are coded in the predictive mode in the intra-slice coding algorithms, the picture size becomes large when the motion compensation fails and the macroblock is coded in the intra mode. The scene change also affects the generated traffic in the VBR coding algorithm, where the static quantizer scale is employed. In the case of the CBR and CBR intra-slice coding algorithms, because of the quantization based rate control, the influence can be avoided to some extent. Those characteristics are observed in the simulation experiments in Section 3.

3 Comparison among coding algorithms

In this section, we compare four coding algorithms by considering traffic characteristics, the video quality and the end-to-end delay.

3.1 Overview of comparison

The traffic characteristics we consider include the mean, maximum, minimum rate in Mbps and the variance. The video quality is evaluated with the subjective measurement, SNR.

As precisely explained in the below, the end-to-end delay consists of the processing delay for picture format conversion, encoding/decoding and packetizing/depacketizing, the network propagation delay, the packet reordering and the buffering delay for smoothing. However, in this paper we only consider the packet reordering, the buffering delay for smoothing and the packet transfer delay as shown in Fig. 7 under the assumption that the other process can be implemented on the hardware and the processing delay is dependent on the architecture. The network propagation delay is also omitted in our comparison because it is identical among all coding algorithms. Figure 6 shows the system model and Fig. 7 illustrates the example of delay involved in the video transfer. The GoP structure in the example is IBBPBB (N=6, M=3) and the frame rate is 29.97 fps. The sending end station first captures the original picture from input device (camera, LD, VCR) with the regular interval, i.e., 1/29.97 seconds. Then, the captured pictures are coded as I, P or B picture dependent on the defined GoP structure. In this example, the first two pictures, 0 and 1, are to be coded as B pictures. Thus, the third picture I2 should be coded prior to them, because they refer to I2. Similarly, coding picture P5 is ahead of B3 and B4. As shown in this example, the picture reordering is required and the extra buffering delay is introduced when the GoP contains B pictures. The reordering is also necessary at the receiving end station.

The coded pictures are then emitted after being smoothed in the buffer to fit to the allocated bandwidth. If the bandwidth larger than the peak rate of the coded video traffic is allocated, the coded pictures are directly injected into the network and no buffering is involved. Otherwise, the smoothing control must be employed for the data emission rate not to exceed the allocated bandwidth. In the example, the picture I2 or the first coded picture, is smoothed for emission and the buffering delay is introduced. The pictures B0 and B1 are buffered and emitted immediately after I2.

The receiving end station receives picture data and decode them with the regular interval. The first picture B0 can be immediately decoded and displayed because the reference picture I2 has been already received and decoded. If B1 has been received in 1/29.97 seconds after displaying preceding picture B0, it is decoded and displayed. Then, the picture I2 is displayed after 1/29.97 seconds interval. Only if picture data arrive at the receiving end station within the specified interval, the video stream can be played out continuously. However, as shown by the “Immediate Play” line in Fig. 7, when delays incurred by picture reordering and smoothing are too large, the picture data cannot arrive at the receiving end station in time. Then, the continuity and smoothness are broken in the video presentation. To give the high quality and continuous video presentation, the receiving end station should wait for the while before displaying the first picture as in “Deferred Play”. In this paper, we call the waiting time before starting video playout to accomplish the continuous video presentation “end-to-end system delay”.

In simulation experiments, we consider five reference video data used in standardization bodies, i.e., “Bus Crossing Columbus Circle”, “Flower Garden”, “Mobile&Calendar”, “Table Tennis” and “Popple” (704x480 pixels). Additional five video data obtained from LDs, i.e., “Basket Ball”, “Police”, “Star Wars”, “Comedy” and “Animation” (640x480 pixels) are also used. Every video consists of 150 frames and the frame rate is 29.97 fps. Five out of ten, Bus, Flower, Mobile, Popple and Basket, do not contain any scene change and the others do one or more scene changes. For fair comparison, the refreshing cycle in the intra-slice coding algorithms is fixed at 30 and the GoP size N in the VBR and CBR coding algorithms is also 30. To investigate the effect of the GoP structure, three different GoP structures are considered. Those are M=1 (IPP$\cdots$), 2 (IBPBP$\cdots$) and 5 (IBBBBPBBBBP$\cdots$).

3.2 Comparison on traffic characteristics

The traffic characteristics of coded video data on “Bus Crossing Columbus Circle” are summarized in Table 1. In comparison, the target rate in the CBR and CBR intra-slice coding algorithms is specified as 5.32 Mbps. The quantizer scale in the VBR and VBR intra-slice coding is 6 to keep the average rate about 5.32 Mbps. As shown in the table, the variance in the intra-slice coding algorithms is small and the maximum rate is also small. On the other hand, the VBR and CBR coding algorithms cause the high rate fluctuation observed in picture by picture. Especially in the case of the CBR coding, the rate variation is largest when the the number of B pictures in a GoP is large because of the picture type dependent rate control.

To see the influence of scene changes on the traffic characteristics, results on “Table Tennis” are also summarized in Table 1. The scene change causes a sudden rate increase in the VBR and VBR intra-slice coding algorithms (for VBR intra-slice, see Fig. 5), and therefore variance increases as shown in the table. The CBR intra-slice coding algorithm is the most effective among four, in that the rate increase caused by the scene changes can be avoided by the quantization control method and there is no GoP related rate fluctuation. The variance is the smallest among coding algorithms on both “Bus” and “Table”. Although results are not shown in the paper, the same tendency was observed in the other video data. Thus, the low delay video transfer over the allocated bandwidth can be expected by employing the CBR intra-slice coding algorithm, because the smaller rate fluctuation leads to the smaller smoothing delay.

3.3 Comparison on video quality

The comparison results on the video quality under the same condition as in Table 1 are summarized in Table 2. As shown in the table, the video coding algorithms which employ the fixed quantizer scale, i.e., the VBR and VBR intra-slice coding, achieve higher and more stable quality than the others. The difference becomes obvious when they are applied to the video data with scene changes. See the column "Table" in the table. The picture quality varies much in the CBR and CBR intra-slice coding algorithms which employ the quantization based rate control method. Even if the maximum picture quality is high, users may feel uncomfortable with the video presentation of unstable quality. From observations and experiments on the other video data, we conclude that the coding algorithms without the quantization control should be employed to have the better presentation quality.

3.4 Comparison on end-to-end system delay

As described in Subsection 3.1, the receiving end station has to defer the video playout to realize the continuous presentation, that is, it should consider the end-to-end system delay which consists of the picture reordering delay and the smoothing delay as shown in Fig.7. The end-to-end system delay introduced in the video transfer over the connection of 5 Mbps is shown for all coding algorithms in Table 3. We should note that the average rate in all coding algorithms is lower than the allocated bandwidth. In the CBR and VBR coding algorithms, the end-to-end system delay becomes longer as the number of B pictures in a GoP increases because coding B pictures is deferred until the reference picture is coded (picture reordering delay).

When comparing the coding algorithms with and without the rate control, the former can start video playout earlier. Especially when the video data contains scene changes as in the case of "Table", the end-to-end delay without the rate control becomes considerably large. Considering the fact that the propagation delay must be taken into account in addition to the end-to-end system delay before displaying the first picture in an actual situation, the end-to-end system delay should be as small as possible. Consequently, the CBR intra-slice coding algorithm is most preferable for the interactive video application. It is true that both CBR and VBR coding algorithms with $M = 1$ where no inter-picture coding is performed could achieve smaller end-to-end system delay than intra-slice coding when we consider delay for the coding/decoding processes. However, when those processes are implemented on ASIC (Application Specific Integrated Circuit), those delays should be smaller than several milliseconds and the intra-slice coding algorithm provides better QoS.

4 Video transfer with consideration on application level QoS requirements

To achieve the effective and impressive video presentation in distributed multimedia applications via bandwidth reservation based networks, video coding must be performed with the appropriate coding algorithm while considering the application level QoS (Quality of Service) requirements in terms of the perceived video quality and the end-to-end delay. For example, smaller quantizer scale and much allocated bandwidth can provide users with the high quality and low delay video presentation as far as the receiving end station has enough processing power. However, the bandwidth the connection can occupy is limited according to the network congestion level because the network resource is shared among connections. Further, to efficiently utilize network resources, the bandwidth to reserve should be as close as the average rate of the video traffic, not the peak. By reducing the bandwidth to reserve, the possibility of successful reservation becomes large and the number of connections simultaneously multiplexed on the link can be increased. When the allocated bandwidth is smaller than the peak rate of the video traffic, the sending end station should employ the smoothing control method to regulate the data emission rate. For the applications which require as small delay as possible, such as the interactive video conferencing, the video quality should be intentionally degraded, but still higher than the required QoS, to reduce the smoothing delay by decreasing the coded video rate.

In this section, based on the observations in Section 3, we investigate the coding algorithm suitable for the video transfer guaranteeing the application level QoS requirements.

4.1 Relationship between average rate and video quality

In this subsection, by investigating the relationship between the average rate and the video quality, we find the coding algorithm which achieves the highest video quality on the allocated bandwidth. The results are depicted in Figs. 8 through 10 for video data “Bus Crossing Columbus Circle”, “Popple” and “Mobile&Calendar”.

As shown in Figs. 8 and 9, the achievable video quality in the VBR and VBR intra-slice coding algorithm is higher than those in the CBR and CBR intra-slice when the average rate is the same. That is, the higher video quality can be obtained by the coding algorithm with fixed quantizer scale when the static bandwidth is allocated to the connection if the end-to-end system delay does not matter. Further we can observe in Fig. 8 that the average SNR becomes higher with larger M as the allocated bandwidth is smaller than 7 Mbps in the CBR coding algorithm. On the other hand, insertion of B pictures always results in the degradation of video quality in “Popple”. This is because that “Bus” is relatively motionless and the compression algorithm of B picture works well while the motion compensation often fails in the active video “Popple”. Videos “Flower Garden”, “Table Tennis” and “Comedy” show the same tendency as “Bus”. Since other videos “Animation”, “Basket”, “Police” and “Star Wars” are also active as “Popple”, those exhibit the same characteristics. In the case of “Mobile”, where contents of picture changes very slowly, the compression algorithm of B picture works very well and the GoP with more B pictures always leads to better video quality as shown in Fig. 10.

4.2 Relationship between average rate and end-to-end system delay

In this section, we investigate the relationship between the average rate and the end-to-end system delay. Three values of the bandwidth allocated to the connection are used; 2, 5 and 10 Mbps in Figs. 11, 12 and 13, respectively. As shown in those figures, the GoP structure with B pictures leads to the large end-to-end system delay because of the picture reordering. The tendency is independent on the coding algorithms. In Fig. 11 where only 2 Mbps bandwidth is allocated to a connection, the smallest end-to-end system delay can be achieved by the VBR intra-slice coding algorithm. However, the delay drastically increases in the VBR and VBR intra-slice as the average rate becomes large because the burstiness of the coded video traffic increases. Although the rate averaged over GoP is kept around the allocated bandwidth in the CBR coding algorithm, the delay is relatively larger than the VBR coding especially when $M = 5$. This is because the picture-basis rate fluctuation is larger than that of the VBR as shown in Table 1. In most cases, the CBR intra-slice coding algorithms achieve the lowest delay among four. However, as having been shown in Subsection 4.1, the video quality deteriorates in that algorithm.

4.3 Relationship between end-to-end system delay and video quality

In Subsection 4.1, we conclude that the high quality video transfer can be accomplished by the VBR and VBR intra-slice coding algorithms. Further, it is shown in Subsection 4.2 that the CBR intra-slice coding algorithm is preferable for the application with the strict QoS requirement on the end-to-end system delay. In this section, we investigate the coding algorithm which enables the video transfer over the statically allocated bandwidth while guaranteeing the application level QoS requirements on the video quality and the end-to-end system delay.

In Fig. 14, we show the relationship between the end-to-end system delay and the video quality for the video data “Bus” on the connection of 5 Mbps. From the figure, we can find the appropriate coding algorithm and parameters which accomplishes the video transfer satisfying the application level QoS requirement on the end-to-end system delay. “MQ INTRA” in Figs. 14 through 16 is the modified VBR intra-slice coding algorithm which will be mentioned in the next subsection. It is obvious from Fig. 14 that introducing B pictures in the GoP results in longer delay. For the video data “Bus”, the coding algorithms without the rate control, i.e., the VBR (M=1) and VBR intra-slice coding algorithms outperform the others. In the case of “Mobile” where B picture compression is effective (see Subsection 4.1), on the other hand, the CBR coding with B pictures (M=5) obtains the highest video quality when the allowable delay is longer than 300 msec as shown in Fig. 15.

The coding algorithm other than the VBR and VBR intra-slice becomes the most effective when the video contains scene changes and the allowable end-to-end delay is small. For example, in Fig. 16, all coding algorithms are applied to the video data “Table” which consists of three scenes. Results for “CBR (M=5)” and “VBR (M=5)” do not appear in the figure because it is magnified to have a closer look. As shown in the figure, the CBR intra-slice coding algorithm outperforms the others when the allowable end-to-end delay is longer than 35 msec. This result comes from the fact that the traffic fluctuation of the CBR intra-slice coding algorithm is the smallest among all for the video with scene changes as shown Table 1. The smaller rate fluctuation leads to the smaller smoothing delay.

We conclude that the VBR intra-slice coding coding algorithm is preferable for the video without scene changes and the CBR intra-slice is for the video with scene changes when the end-to-end system delay which the application can tolerant is relatively small. Thus, by employing the VBR intra-slice or CBR intra-slice coding algorithm, the high quality and low delay video transfer can be provided for the real-time interactive applications such as a video conferencing.

4.4 MQ intra-slice coding algorithm

One point we should notice is that in the VBR intra-slice coding algorithm the first picture has the largest size among all coded pictures because it is coded in an intra mode like I picture. The picture size directly affects the smoothing delay at the sending end station. Thus, it must be effective to reduce the size of the first picture to achieve the smaller end-to-end system delay especially for the video data without scene changes. We introduce an easy and straightforward modification to the VBR intra-slice coding algorithm. In our modified VBR intra-slice coding, which is called "MQ intra-slice coding algorithm", the doubled quantizer scale is applied to the first picture. A rationale behind this is that only the very fast part of the video with degraded quality dose not affect the user's perceived video quality.

The comparison between the VBR intra-slice and MQ intra-slice coding algorithms is shown in Figs. 17 and 18 where the quantizer scale is 6. As shown in Fig. 17, the size of the first picture becomes small in the MQ intra-slice coding because the quantizer scale of 12 is applied. As a result of the higher quantization, the quality of the first picture deteriorates (see Fig. 18). However, the intra-slice coding can recover from the quality degradation by rotating the intra slice and the picture quality becomes the same in five pictures time (about 167 msec) in the example.

The relationship among the achievable video quality against the allowable end-to-end system delay in the MQ intra-slice coding algorithm is depicted in Figs. 14, 15 and 16 for videos "Bus", "Mobile" and "Table", respectively. The MQ intra-slice coding algorithm shows the highest average SNR values in all figures. This result means that the MQ intra-slice is the most effective coding algorithm in achieving the high video quality on the allocated bandwidth when the allowable end-to-end delay is small. Even in the video with scene changes (Fig. 16), the quality of the MQ intra-slice coded video is the highest when the tolerable delay is smaller than 75 msec. Especially in "Bus" and "Mobile", the achievable video quality increases as mush as 4 dB.

5 Conclusion

In this paper, we investigated the most effective coding algorithm in transferring the coded video data over the statically allocated bandwidth considering the application level QoS requirements on the video quality and the end-to-end delay. By comparing four coding algorithms, i.e., CBR, VBR, CBR intra-slice and VBR intra-slice, we have shown that the intra-slice coding algorithms can provide applications with the high quality video transfer while guaranteeing

QoS requirements on the end-to-end system delay.

Further, we have introduced the easy and straightforward modification to the VBR intra-slice coding algorithm to decrease the influence of the first coded picture size on the smoothing delay. Although it is not our intention to insist on the MQ intra-slice coding algorithm, by applying the proposed algorithm, the video transfer of higher quality can be accomplished for the small tolerable delay. However, in the MQ intra-slice coding algorithm, it is still unavoidable that the instantaneous and drastic explosion of picture size occurs when a scene changes. Such explosion causes the long end-to-end system delay, or disturbs the continuous video presentation. We are currently investigating the rate control algorithm which dynamically regulate the quantizer scale reacting to scene changes.

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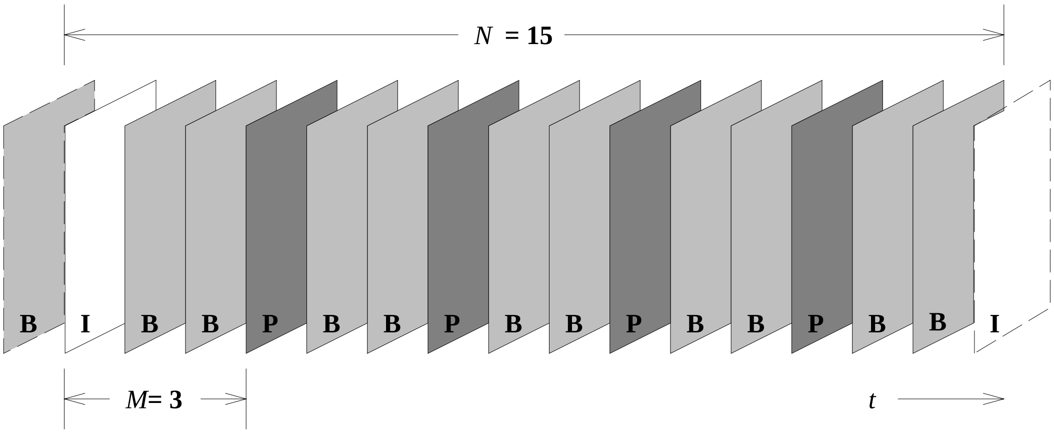

Fig. 1. GoP structure

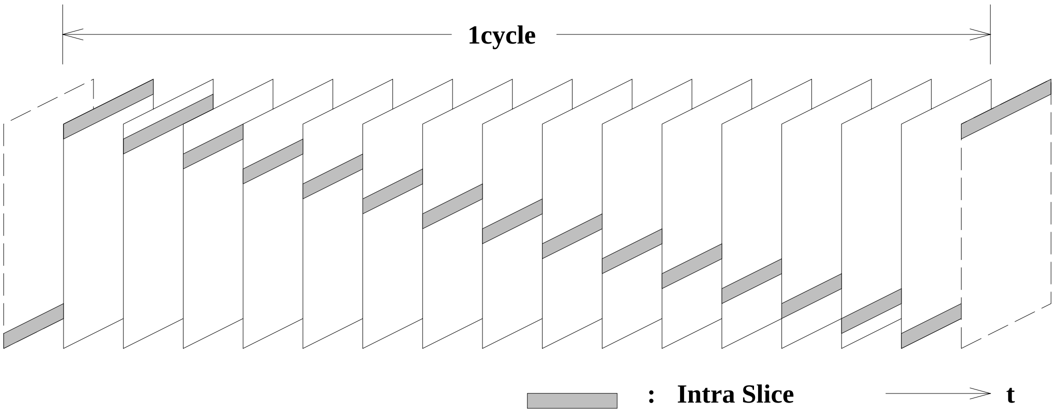

Fig. 2. Intra slice coding

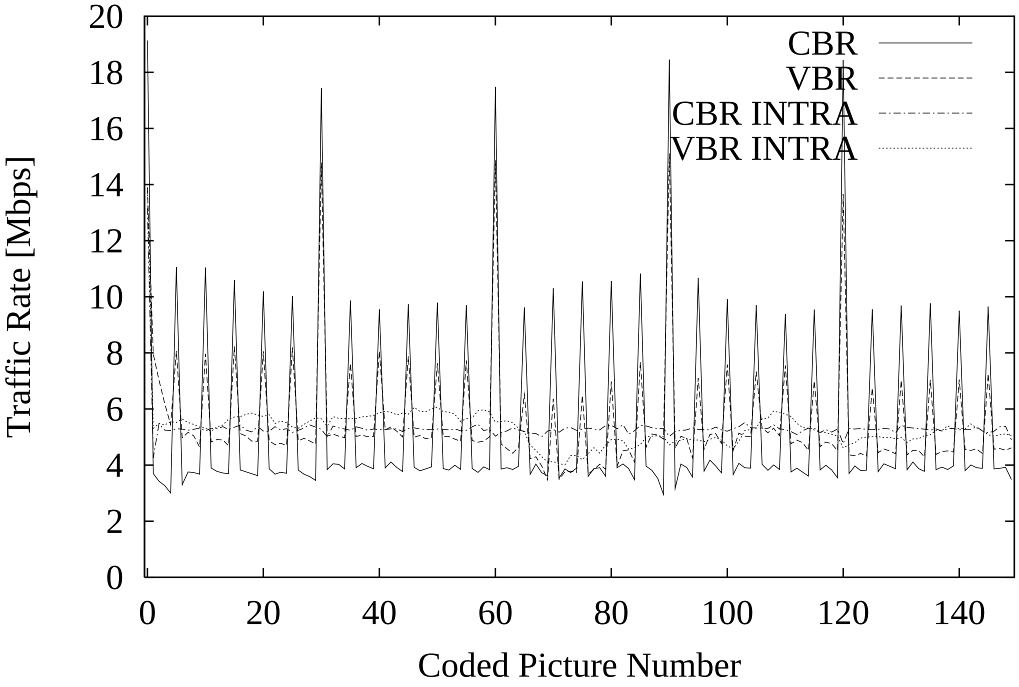

Fig. 3. Coded video traffic

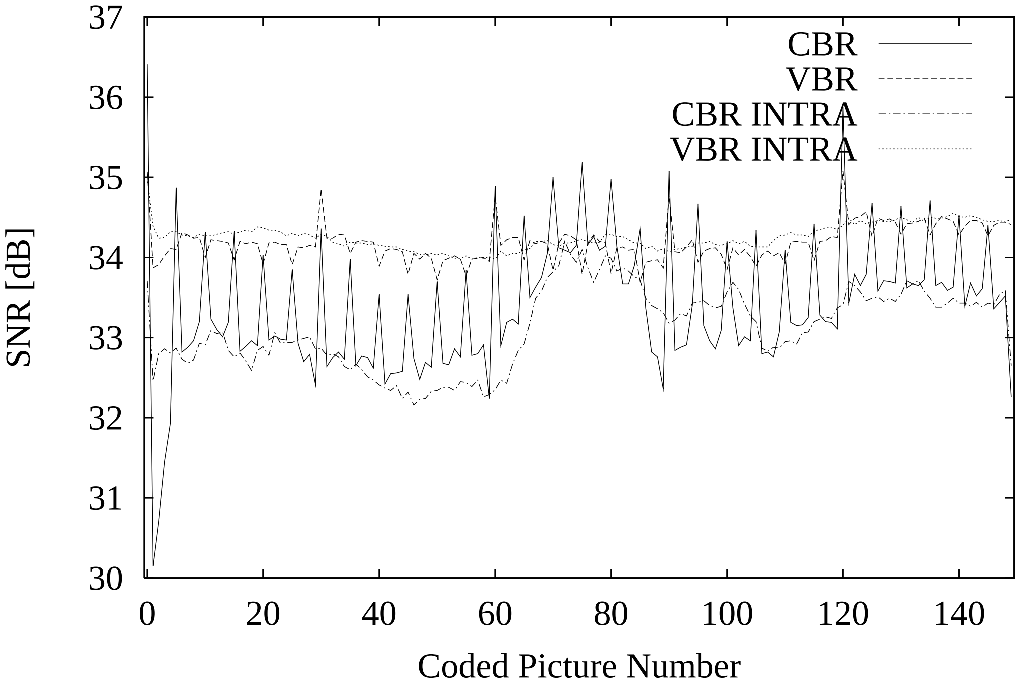

Fig. 4. Coded video quality

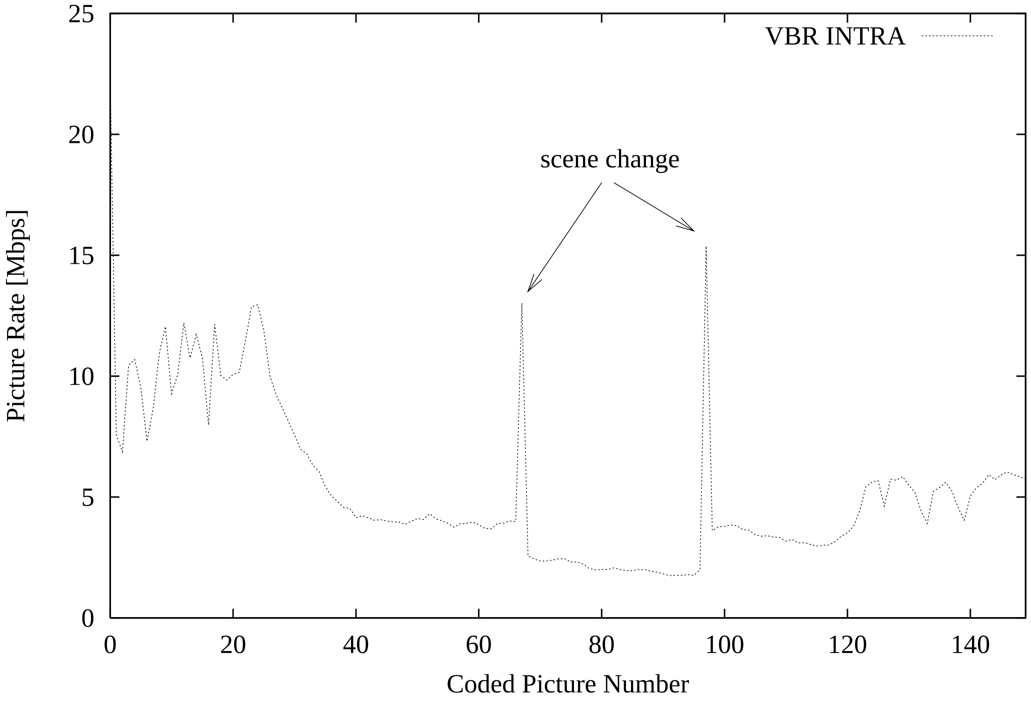

Fig. 5. Example behavior caused by scene change

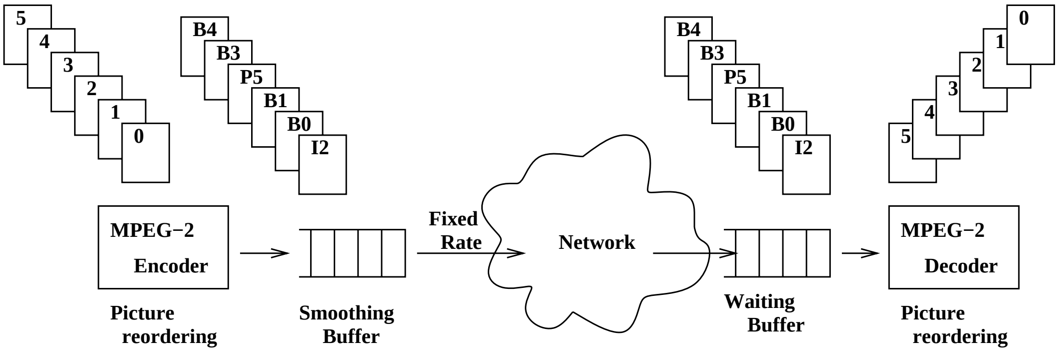

Fig. 6. System model

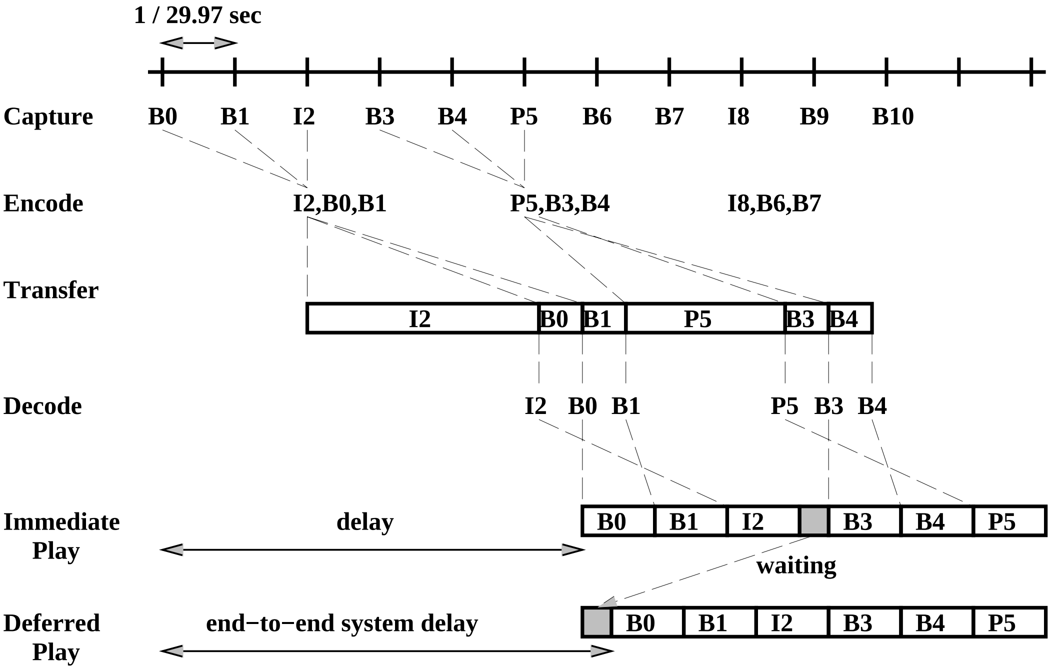

Fig. 7. Delays in video transfer

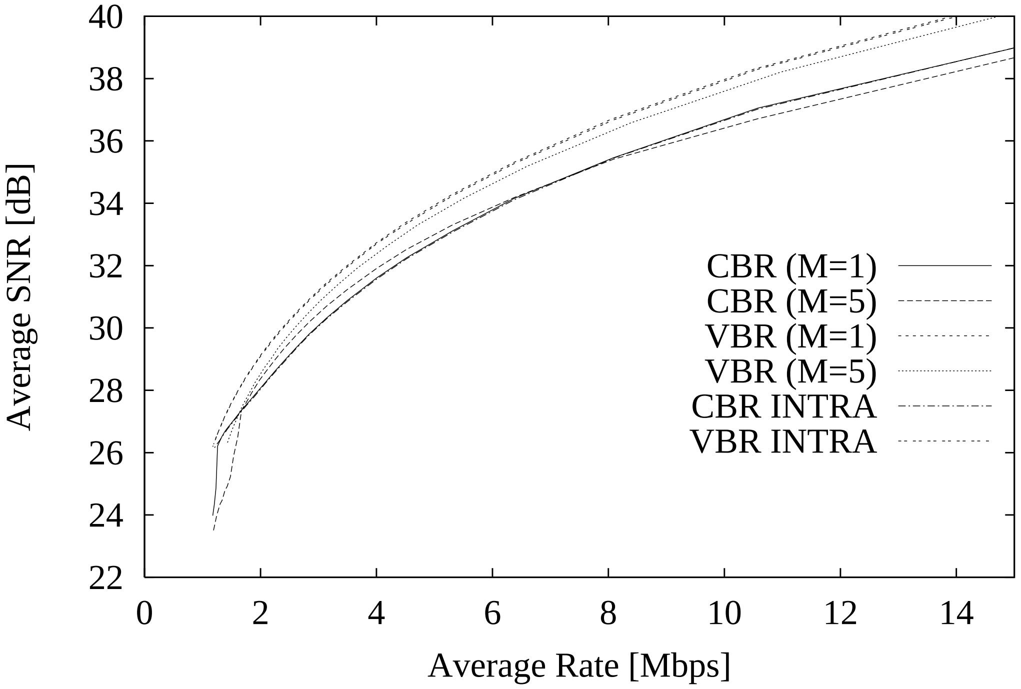

Fig. 8. Relationship between average rate and video quality (Bus)

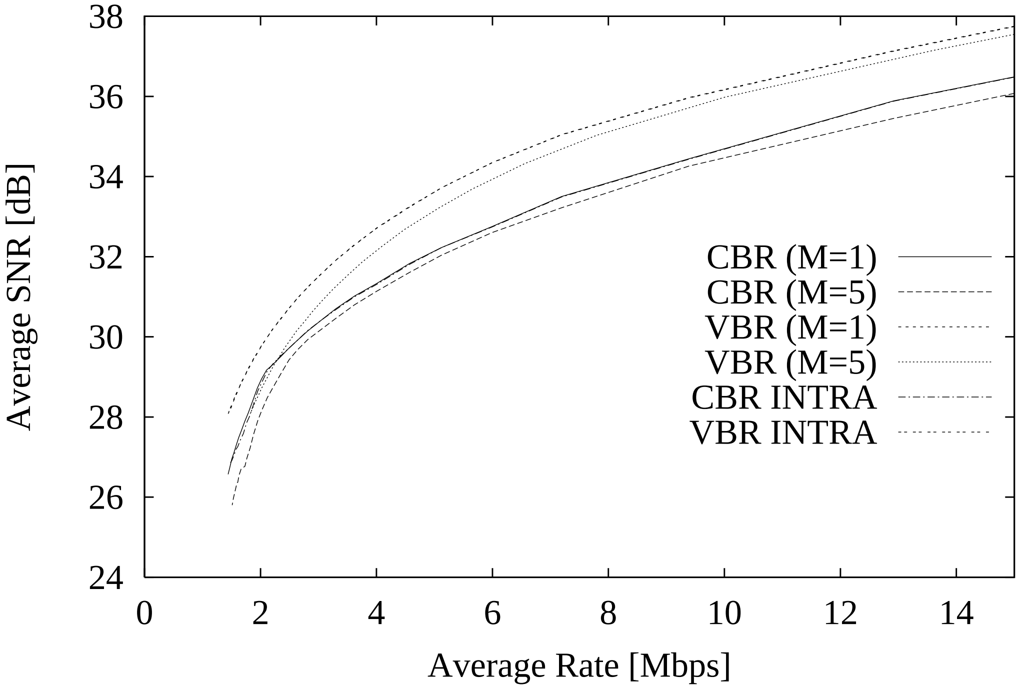

Fig. 9. Relationship between average rate and video quality (Popple)

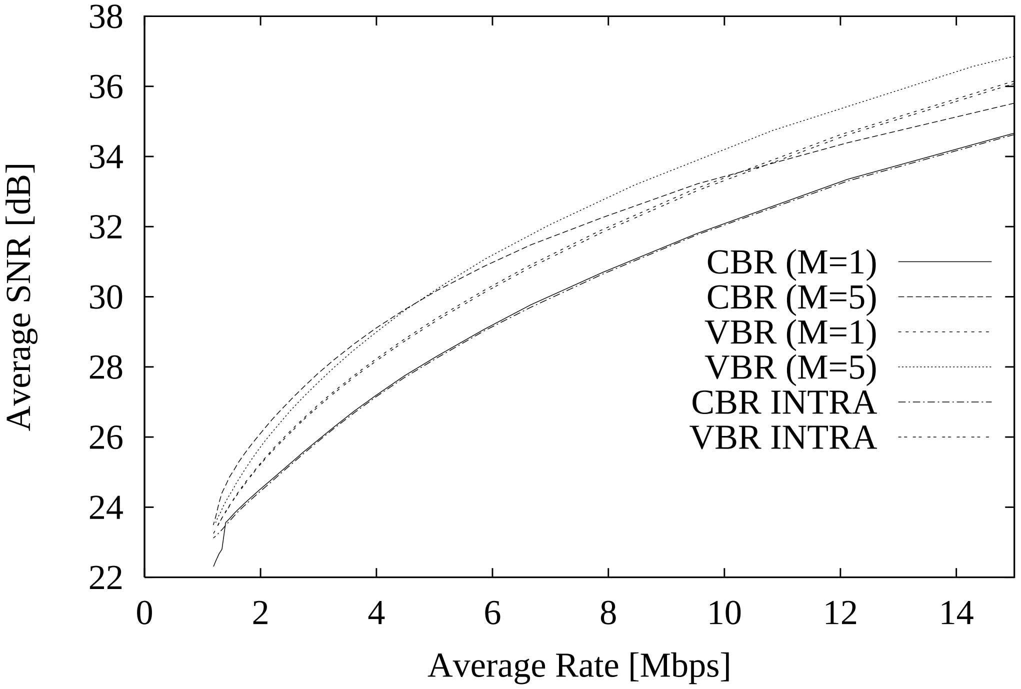

Fig. 10. Relationship between average rate and video quality (Mobile)

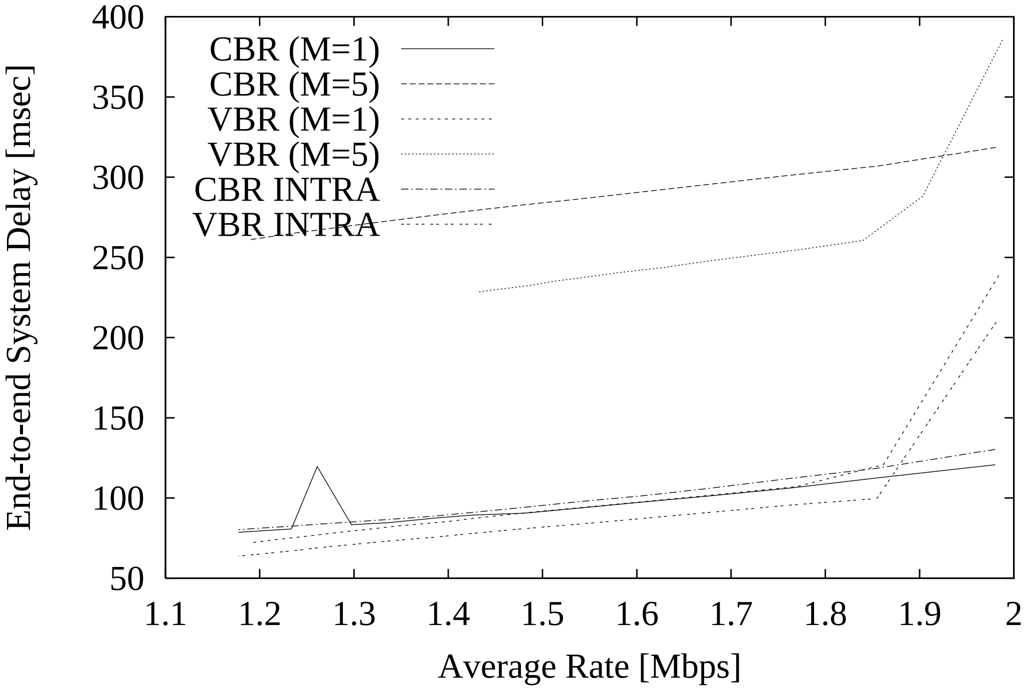

Fig. 11. Relationship between average rate and end-to-end system delay (2 Mbps)

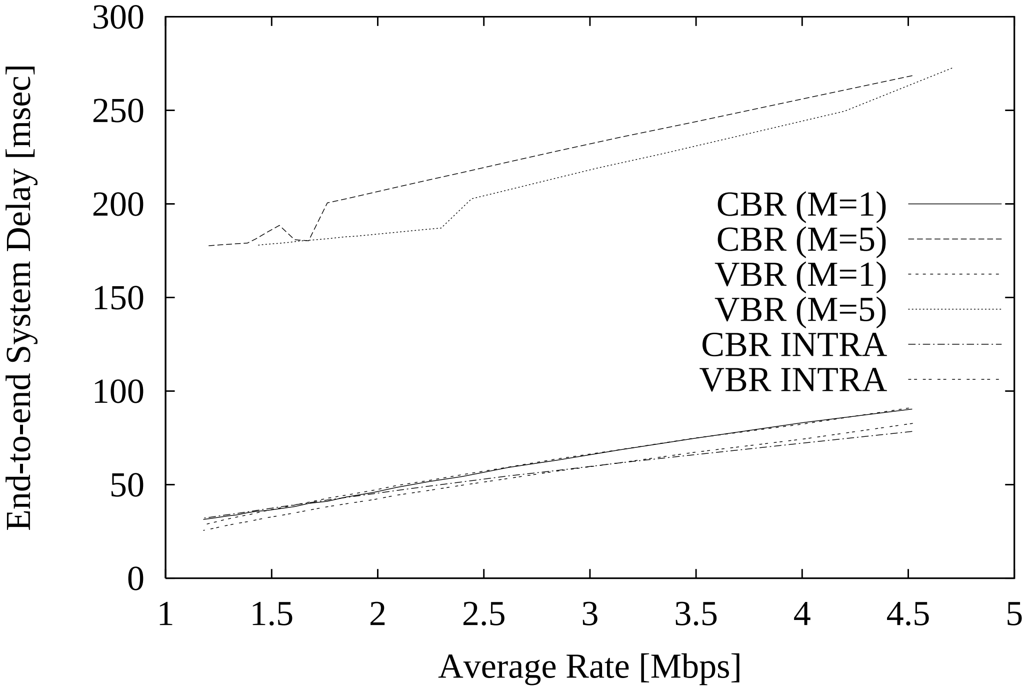

Fig. 12. Relationship between average rate and end-to-end system delay (5 Mbps)

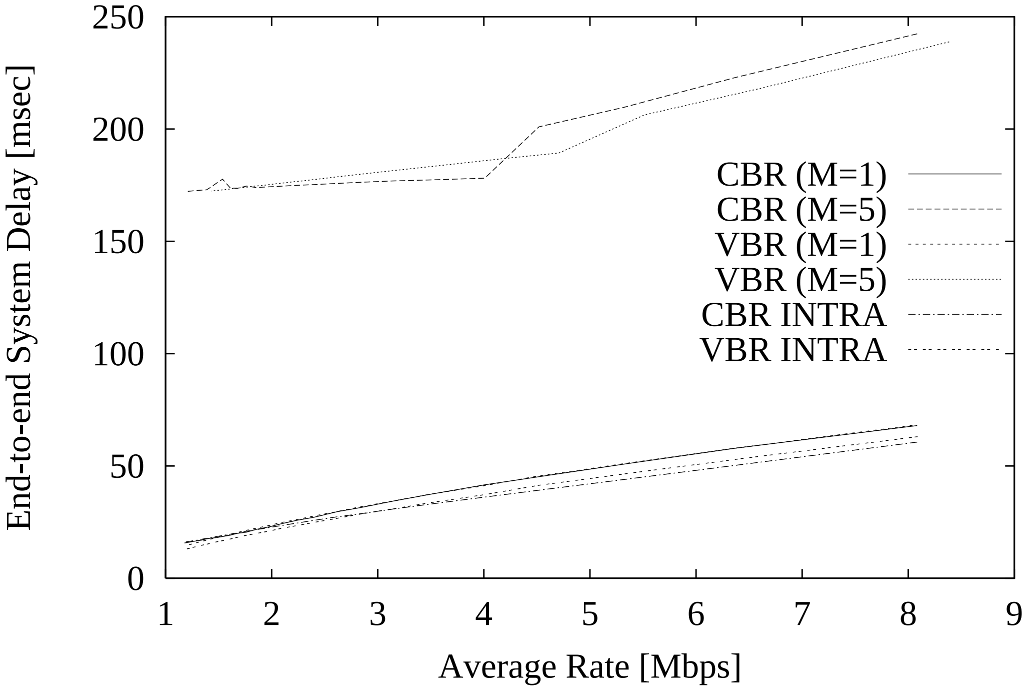

Fig. 13. Relationship between average rate and end-to-end system delay (10 Mbps)

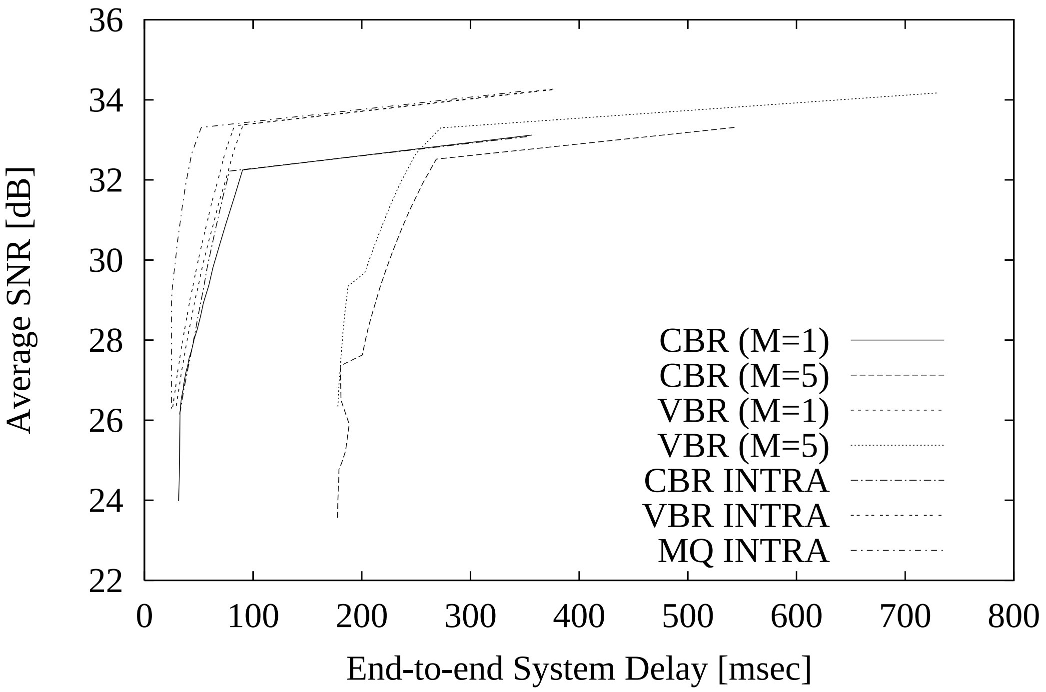

Fig. 14. Relationship between end-to-end system delay and video quality (Bus)

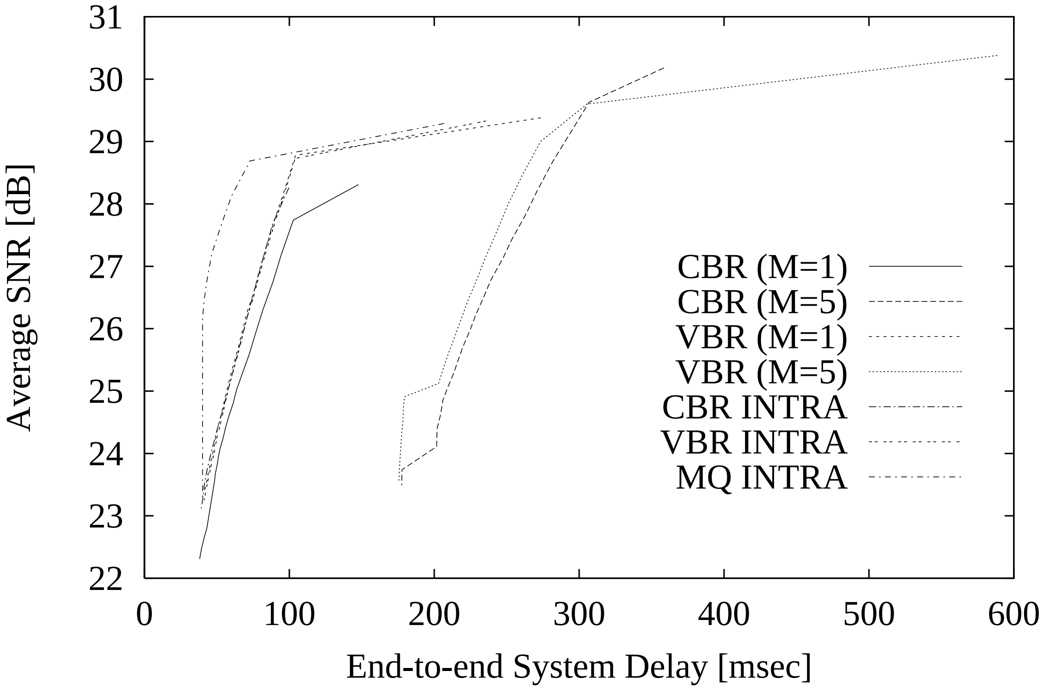

Fig. 15. Relationship between end-to-end system delay and video quality (Mobile)

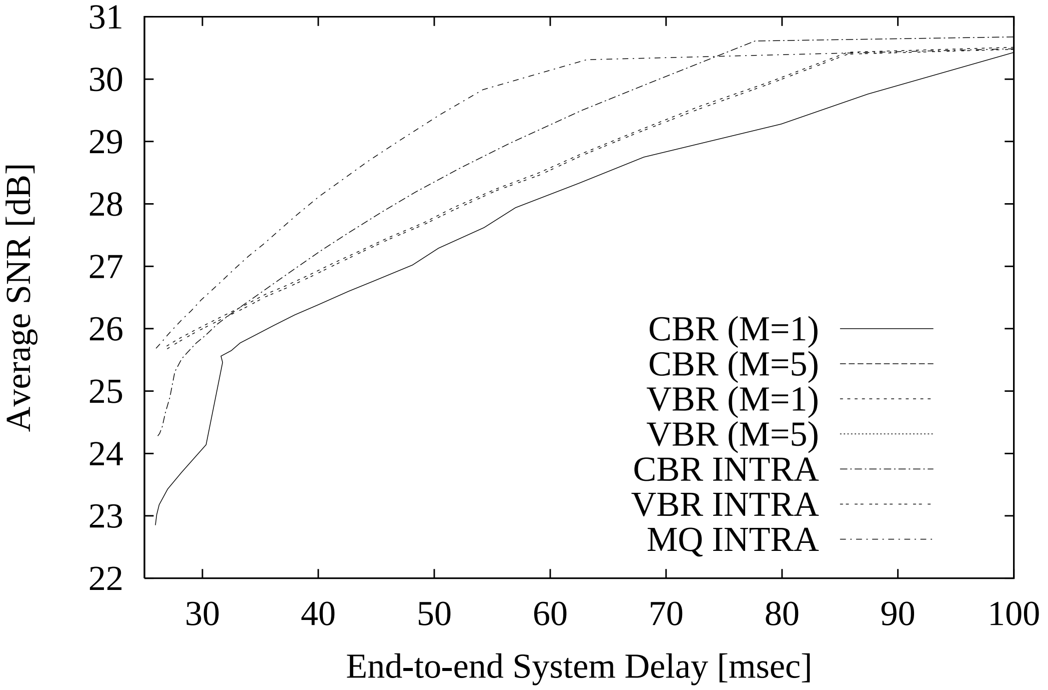

Fig. 16. Relationship between end-to-end system delay and video quality (Table)

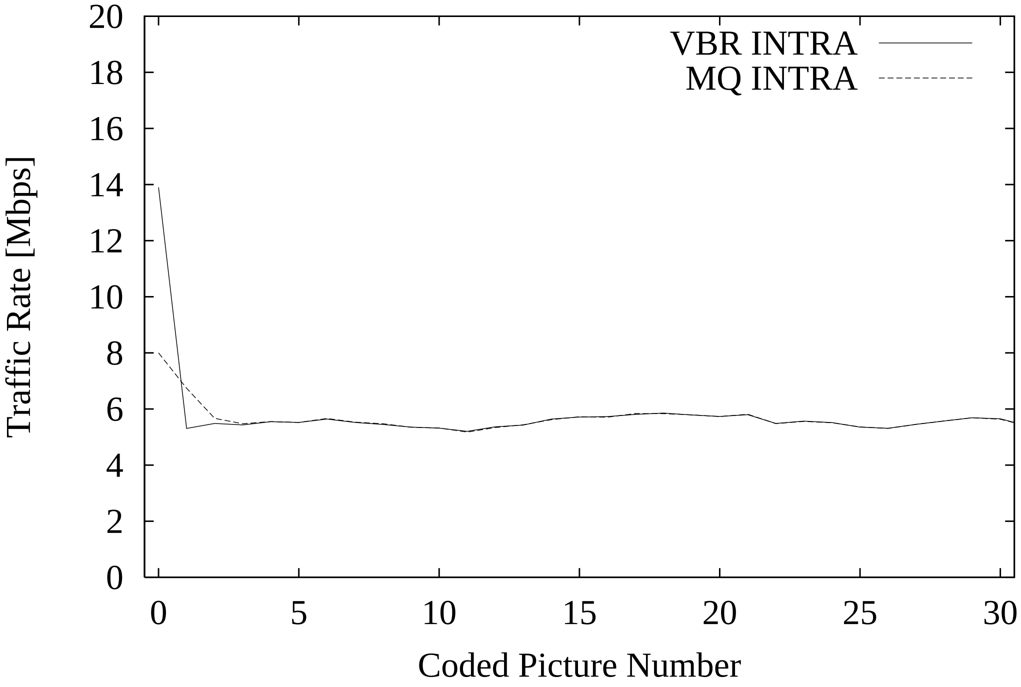

Fig. 17. Rate variation in MQ intra-slice

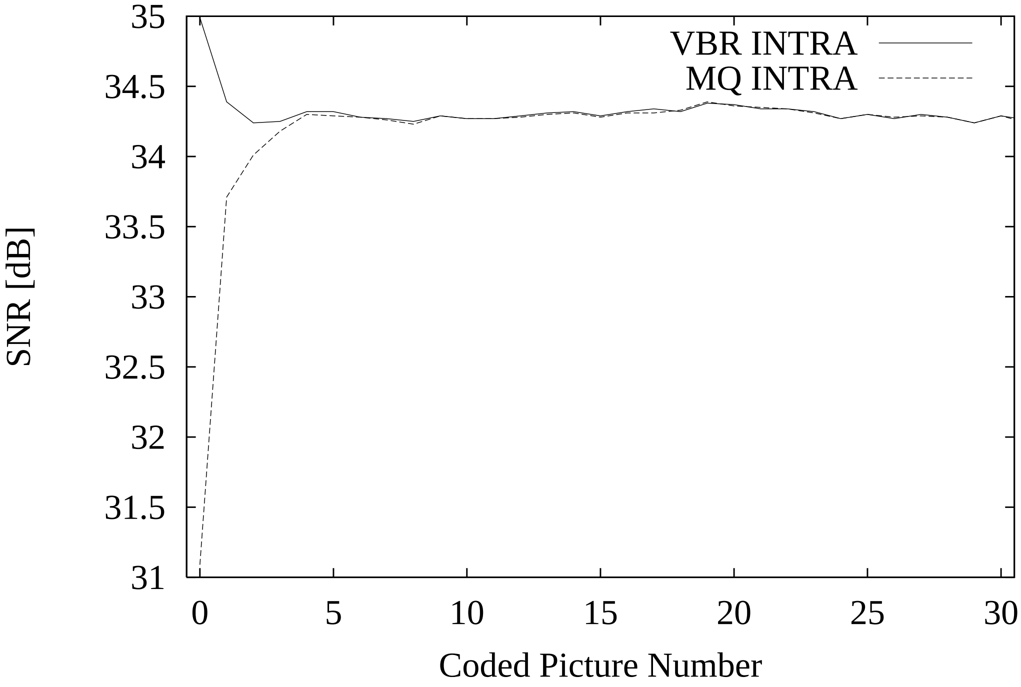

Fig. 18. SNR variation in MQ intra-slice

Table 1
Traffic characteristics (Bus, Table) [Mbps]

	Bus				Table			
Coding algorithm	Mean	Min	Max	Var	Mean	Min	Max	Var
CBR $(M = 1)$	5.32	4.13	15.22	2.657	5.35	3.36	16.90	3.293
$(M = 2)$	5.32	2.13	16.87	8.891	5.34	1.47	18.42	10.822
$(M = 5)$	5.32	2.95	19.13	11.156	5.35	2.39	19.55	13.276
VBR $(M = 1)$	5.29	3.84	15.24	3.156	5.46	1.87	22.39	12.625
$(M = 2)$	5.39	2.71	15.22	4.278	5.46	1.54	22.67	13.161
$(M = 5)$	5.51	3.47	15.10	4.035	5.79	1.88	22.23	13.687
VBR intra-slice	5.32	4.01	13.90	0.717	5.35	1.75	22.39	11.146
CBR intra-slice	5.32	4.25	13.18	0.431	5.35	3.74	13.41	0.549

Table 2
Video quality (Bus, Table) [dB]

	Bus				Table			
Coding algorithm	Mean	Min	Max	Var	Mean	Min	Max	Var
CBR $(M = 1)$	33.15	32.19	34.53	0.291	32.42	26.61	37.59	8.166
$(M = 2)$	33.27	30.87	35.43	0.477	32.98	26.66	37.98	6.813
$(M = 5)$	33.29	30.15	36.41	0.699	33.01	25.78	37.79	7.535
VBR $(M = 1)$	34.27	33.94	35.10	0.035	34.14	32.17	35.82	1.008
$(M = 2)$	34.17	33.58	35.10	0.079	34.14	32.19	35.82	0.939
$(M = 5)$	34.18	33.69	35.08	0.052	34.11	32.17	35.75	0.918
VBR intra-slice	34.25	34.99	33.98	0.025	34.12	32.17	35.55	1.003
CBR intra-slice	33.11	34.20	32.16	0.247	32.54	26.76	35.81	8.132

Table 3
End-to-end system delay (Bus, Table) [msec]

	CBR				VBR			
Video	M=1	M=2	M=5	Intra	M=1	M=2	M=5	Intra
Bus	90.4	149.2	268.5	78.4	90.9	148.0	272.6	82.8
Table	100.8	156.5	272.9	77.7	831.5	874.4	1136.2	808.9