Recommendations for Switching Frames in Mobile Video Streaming

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ABSTRACT
Real time multimedia application is a challenging issue in the mobile networks, due to high compression requirements and limited and varying channel bandwidth. H.264/AVC addresses these issues with its excellent coding efficiency, error resiliency features and provision of bit rate adaptivity, using switching (SP-) frames. To reduce the quantization errors due to multiple quantization, SP- frames are usually coded with finer quantization parameters (QP) than the rest of the sequence, resulting in an increased bit rate, sometimes exceeding to that of intra (I-) frames. This limits the basic advantages of SP-frames over I-frames and that is better coding efficiency, leading to poor utilization of the resources like bandwidth. Thus the question is "what is the safe range of QP such that the bit rate of the switching frames does not exceed that of the I-frames"? The aim of this paper to suggest a solution to this problem by analyzing characteristics of SP-frames and to suggest a safe range of QP for switching frames ensuring that its bit rate remains lower than that of I-frames.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]: *Network communications---Wireless communication;* H.3.4 [**Information Storage and Retrieval**]: *Performance evaluation (efficiency and effectiveness);* H.5.1 [**Multimedia Information Systems**]: *Video;* I.4.1 [**Digitization and Image Capture**]: *Quantization*

General Terms
Measurement, Performance.

Keywords
Bit stream Switching, H.264/AVC, Switching Frames, Video Streaming, QoS.

1. INTRODUCTION
In Video streaming the video sequences are generally encoded off-line and stored in a server [1]. Users may access these stored videos at any time over a shared channel such as the Internet. To be able to receive and play back the video over such a time varying network, the data rate of the transmitted video is needed to match the varying network conditions [2]. This problem can be alleviated by either adapting the video bit rates with the available channel bandwidth, by configuring the network resources to accommodate the video bit rates through some QoS control mechanisms [3] , adapting the bit rate of the transmitted video according to the available bandwidth, generating scalable bit stream [5] [6] or dynamically switch among the multiple and independently encoded bit streams having different quality and bit rates for the same video [7].

As the stored data usually does not have the property to adapt to the transmission conditions [4]. Therefore to adapt to the available bandwidth H.264/AVC has introduced a new type of frame namely, switching predictive/intra frame (SP/SI-frame) for the drift free switching between the streams, these frames can be reconstructed by using different reference frames or no reference at all as in case of SI-frames [8] [9][11]. Switching frames consists of two versions, namely primary and secondary SP-frames (throughout this paper, they are referred as PSP and SSP frames respectively, while "switching frame" or SP-frame is used to refer to both the frames). The PSP-frames are inserted at the probable switching points, whereas the SSP-frames, which are a mismatch free version of the PSP-frames, are only used when the actual switching occurs. Drift free switching can be done using intra coded frames, but switching frames use motion compensated predictive coding therefore their coding efficiency is better than the I-frames with a relatively lower quality [8][9][10].

This low quality of PSP-frames is due to its double quantization before sending it to the reference frame buffer while the SSP-frame has to follow the quality of the PSP-frame. The second quantization enables the drift free reconstruction of PSP-frame (as SSP) from different reference frames. To reduce the quantization errors, usually the reference PSP-frame is coded with finer (i.e. reduced) quantization parameters, than that used for the original frame [9], leading to an increased bit rate, even surpassing that of the I-frame. If the bit rate of either PSP or SSP-frames exceeds that of I-frames, it will increase the overall bit rate, decreasing bandwidth utilization and hence quality of service in time varying and bandwidth limited channels like mobile networks. This may also increase the delay by increasing the number of packets as high bit rate frames need more packets than low bit rate frames.

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Here the problem is that up to what extent this reduction in quantization parameter of switching frames should be allowed, so that its basic advantage, which is its ability of drift free switching like the I-frames but with lower bit rate, is not sacrificed.

R-D analysis of SP-frames are widely reported in literatures [10][11][12], along with some new methods of coding SP-frames[13], but in most of the papers the selection of quantization parameters are based on the probability of sending either a PSP-frame or SI-frame [11]. To the best of our knowledge, no attempt is made to address the problem of selecting a safe range of QP for SP-frames. This paper attempts to recommend a safe range of QP for the SP-frames, such that its bit rate does not exceed that of I-frames, with an acceptable quality close to P-frames. Extensive simulations are carried out using H.264/AVC to address the issues of the quantization parameter range for switching frames.

Rest of the paper is organized as follows. The switching frame concept is reviewed in section 2. The effects of quantization parameters on the switching frames are discussed in section 3. Section 4 includes simulation results and finally concluding remarks are given in section 5.

2. CONCEPT OF SWITCHING FRAMES

In H.264/AVC, Switching Predictive frame (SP-frame) have been defined for the switching purposes [8][9]. The standard specifies two types of SP-frames, namely primary SP-frames (PSP-frames) and secondary SP-frames (SSP-frames). They use motion compensated predictive coding and thus have better compression efficiency than the I-frames. PSP-frames are similar to standard P-frames and SSP-frames have special encoding which leads to the same reconstructed picture as the PSP-frame from a different reference frame [12].

To enable drift-free switching, the streaming server stores the same sequences encoded with different quantization parameters and hence of different quality. These bit streams are populated with PSP-frames at the locations where switching is allowed as shown in figure 1. If switching becomes necessary, the SSP-frame is transmitted [8][9]. The arrow in figure 1 indicates that transmission is started with bit stream1 and all frames before the second PSP-frame of bit stream1 are transmitted followed by SSP-frame (switching occurred) and onwards the rest of the transmitted frames are from bit stream2.

The process of encoding primary and secondary SP-frames are shown in figures 2 and 3 respectively [12]. It can be seen from these figures that the PSP-frame is quantized using QSP and QSSP whereas SSP-frame is quantized using only QSSP.

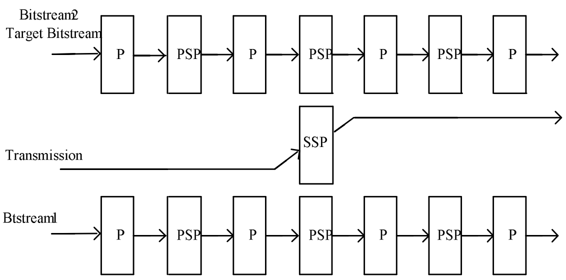


Figure 1. Switching between bit streams using switching frames.

Switching frames are motion compensated frames like P-frames but with one extra quantization, this leads to increased quantization errors and hence decreasing the quality. In fact the second quantization enables drift free reconstruction from different reference frames. To minimize the cumulative quantization errors due to multiple quantizations, switching frames are usually coded with lower value of quantization parameters (QP) as compared to the other frames of the sequence. This reduced quantization parameter may increase the bit rate of the switching frames, some times even more than that of I-frame.

3. R-D ANALYSIS OF SP-FRAMES

To study the effects of QSP and QSSP on the switching frames, a wide range of quantization parameters are tested and the R-D curves of the switching frames are compared with that of the I- and P-frames. The quantization parameters for the switching frames were selected using Eqn. 1 similar to those used in literature [10][12].

$$\left.\begin{aligned} QSP &= QP - i \\ QSSP &= QP - j \end{aligned}\right\} \qquad (1)$$

Where i and j ranges from 0 to QP and QP is the quantization parameter of the rest of the frames of the sequence. Although the QP do not have a direct relation with the value of QSP and QSSP, but as stated earlier, to minimize the effect of two times quantization usually these quantization parameters are taken lower than that of the QP. As discussed earlier QSP affects the PSP-frames and QSSP is used to code PSP-frame before going to

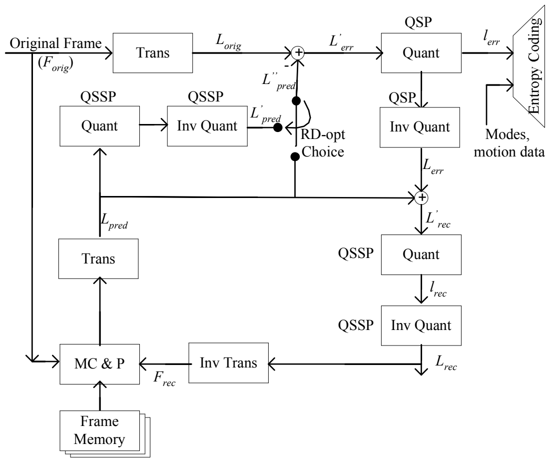


Figure 2. Primary SP-frame encoder

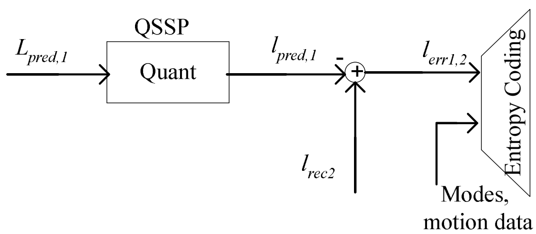


Figure 3. Secondary SP-frame encoder.

reference frame buffer and hence affect the up coming frames for which the PSP-frame is used as reference. The QSSP is also responsible for the drift free reconstruction of the SSP-frame and thus has a direct effect on the value of the SSP-frame. QSP also has an indirect effect on the SSP-frame as it affects the quality of the PSP-frame which the SSP-frame has to achieve as it is an exact reconstruction of the PSP-frame.

Analysis is supported with graphs of QCIF video sequences coded with 10fps having GOP size of 10 frames, coding every 10th frame as I-frame or a PSP-frame. For comparison purposes videos are also coded with out any GOP with all the frames coded as P-frames except for the first, which is coded as I frame.

3.1 PSP-Frame

The R-D curve of the PSP-frames for one GOP are compared with that of I-frames and P-frames for QCIF sequences of "Coastguard" and "Mobile" as shown in figures 4 and 5 respectively. Average PSNR and bit rate of one GOP is plotted in case of I-frames, while for PSP and P-frames the average of 10 frames at the same frame positions as in the other two sequences, is plotted.

The figures show that bit rate of PSP-frames can be as small as P-frames and can even be higher than I-frames depending on the values of QSP and QSSP. Similarly the PSNR may be higher than that of I-frame and even lower than that of P frames. All these curves have the same QP for I and P frames except for the PSP-frames, which occurred only once in a GOP. The values of QP for I and P frames are taken equal to 20, 24, 28 and 32 and that of the QSP and QSSP are taken according to (1) with different values of i and j as given below in Eqns. (2), (3) and (4). The values of i and j are selected arbitrarily for discussion.

$$QSP = QP \quad QSSP = QP \tag{2}$$

$$QSP = QP - 8 \quad QSSP = QP \tag{3}$$

$$QSP = QP \quad QSSP = QP - 8 \tag{4}$$

Considering the curve in Figures 4 and 5, corresponding to Eqn. (2) with the value of QSP and QSSP equal to that of QP, it can be observed that the PSNR is less than that of the P-frames as can be expected due to double quantization of PSP-frame with bit rate less than the I-frames.

In Eqn. (3) the value of the QSP is much lower than that of the QP while QSSP is equal to QP. As the QSP is the main quantization parameter of the PSP-frame, hence its decrease increases the bit rate and PSNR of the PSP-frame increasing the average bit rate and the PSNR of the GOP, which is a normal behavior for the main quantization parameter. At lower QSPs, the bit rate of PSP-frame may surpass that of the I-frame making such a lower value of QSP infeasible for use with the PSP-frame. The QSSP is equal to that of the QP and hence is much coarser than that of QSP. Coarser QP of the reference frame (QSSP) as compared to the QP of the current frame being coded (QSP) makes it difficult to extract motion information from a distorted reference frame increasing the number of intra macroblocks in the current frame ignoring the reference frame for motion data estimation, or the error signal between the current frame and the reference frame becomes very high. Combining the increased error signal or intra macroblocks with lower values of QSP results

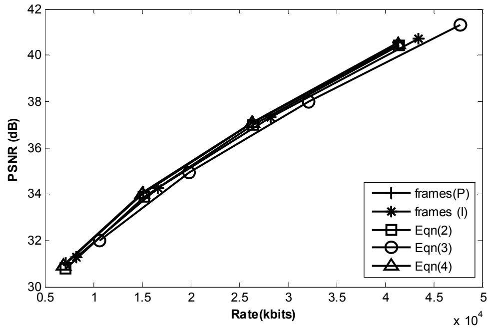


Figure 4. Comparison of PSP-frame with I-frames and P frames for "Coastguard" sequence

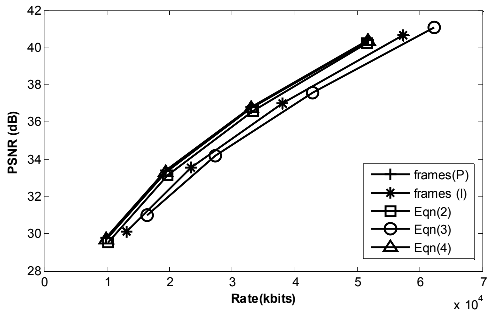
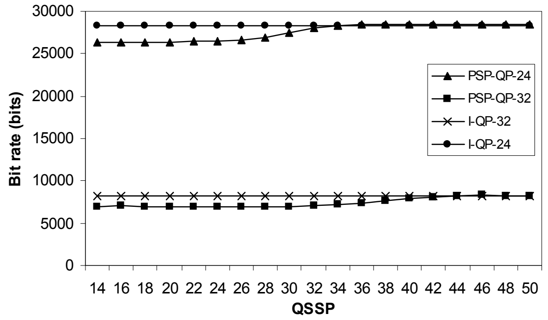


Figure 5. Comparison of PSP-frame with I-frames and P frames for "Mobile" sequence

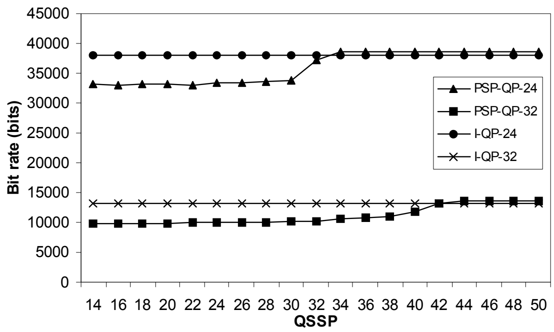
in a high bit rate PSP-frame which can even exceed that of the I-frame as shown in figures 4 and 5 for this particular case.

In case QSP and QSSP are selected according to Eqn. (4), in which the QSP is equal to QP and QSSP is much lower than that of QP, decreasing the quantization errors for second time quantization as compared to that of the (2) and hence improving the quality of the reference frame. This decreases the error signal between the reference and current frame being coded which when quantized with a coarser QSP further decreases the bit rate as can be seen from the figures 4 and 5.

From the above discussion It can be concluded that the effect of the QSP which is the main QP of the PSP-frame is quite straight forward and that is increase in bit rate with the decrease in QSP and vice versa. The effect of the QSSP on the other hand is different as it affects the quality of the reference frame. As we pointed above that coarser QSSP leads to a distorted reference frame that makes it difficult to extract motion information resulting in increase in the number of intra coded macroblocks increasing the bit rate of PSP-frame. This effect can best be seen from figure 6, where the QSP is kept constant and equal to QP, which is equal to 24 and 32 in this case, while the QSSP is varied in a wide range with respect to QP. The x-axis shows the values of



(a)



(b)

Figure 6. Bit rate of PSP frames compared with I-frames (a) "Coastguard" (b) "Mobile"

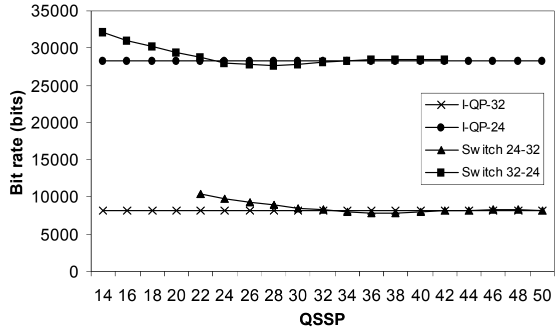
the QSSP having some offset from the QP and the Y-axis shows the bit rate of the PSP and I-frame for the average value over a GOP as was the case in figure 4 and 5. The lowest value of QSSP for which the bit rate of the PSP-frames exceeds that of the I-frames is QP+10 for "Coastguard" and the same for the "Mobile" sequence.

Comparing the results of figures 4, 5 and 6 for a number of sequences with a wide range of QSP and QSSP, it is concluded that for a PSP-frame to have better compression efficiency than the I-frame, the recommended range of QSP and QSSP is given in (5).

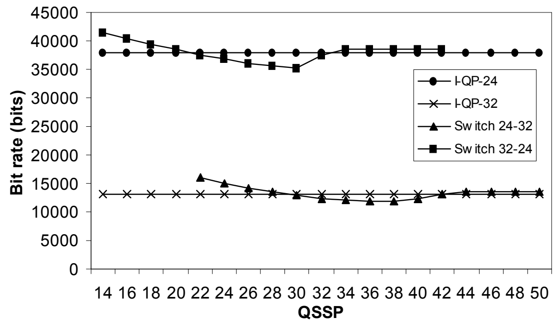
$$
\begin{aligned}
QP - 5 \leq QSP \leq QP + x \\
QP - x \leq QSSP \leq QP + 8
\end{aligned}
\qquad (5)
$$

Where the value of the x is to be decided, this maximum range of the QSP depends on the quality of the PSP-frame, as coarser the QSP lower is the PSNR and the bit rate and hence there is no limit. Therefore here the upper limit of QSP is limited to the value of QP so that the PSNR remains close to that of the P-frames.

The range given in (5) is not a straightforward rule that this value of QSP and QSSP should always fall in this range for all the sequences; there is always a grey area where these values can not be exactly same for all types of sequences. Here in this case there is no such grey area for the given sequences which are very different from each other in both texture and motion, showing that this grey area is not very wide. To complete the discussion and find the value of x for QSSP, the range of QSP and QSSP shown in (5) is furthered studied in the next session for SSP-frames.



(a)



(b)

Figure 7. Bit rate of SSP frames compared with I-frames (a) "Coastguard" (b) "Mobile"

3.2 SSP-Frame

As the SSP-frame is the exact reconstruction of the PSP-frame therefore increasing the quality of PSP-frame also increases the bit rate of the SSP-frame. It can be seen from the curves corresponding to Eqns. (2) and (4) in figures 4 and 5 that decrease in the value of QSSP increases the quality of the reference frame and hence decreasing the bit rate of the PSP-frame. But as QSSP is the main quantization parameter of the SSP-frame, its decrease for better compression efficiency of PSP-frame may lead to increase in the bit rate of the SSP-frame during switching.

Figure 7 shows the effect of QSSP on the bit rate of SSP-frame for the sequences "Coastguard" and "Mobile" for switching from higher quality (QP 24) to lower quality (QP 32) onwards called down switching, and switching from lower quality (QP 32) to higher quality (QP 24) onwards called up switching. X-axis shows the value of the QSSP which is an offset from the main QP of the rest of the sequence while the value of QSP is kept equal to that of QP. Here also the average values for one GOP are plotted like in the figures for the PSP-frame. The bit rate of the SSP-frames exceeds that of I-frames at two points in both the sequences. The points at which the bit rate of SSP-frames exceeds that of I-frames are QP-0 and QP+8 for "Coastguard" sequence and QP-2 and QP+8 for the "Mobile" sequence, in both the up and down switching supporting the upper limit of QSSP in (5).

Table 1: Comparisons of PSP and I-frames for various combinations of QSP and QSSP

Sequence	QSP=QP-1 QSSP=QP		QSP=QP-2 QSSP=QP		QSP=QP-3 QSSP=QP		I-frames	P-frames
	Rate (k bits)	PSNR (dB)	Rate (k bits)	PSNR (dB)	Rate (k bits)	PSNR (dB)	Rate (k bits)	PSNR (dB)
Foreman QP32	2.904	32.46	2.92	32.49	2.98	32.48	4.14	33.00
Akiyo QP20	4.9	43.49	4.95	43.51	5.05	43.51	7.45	44.13
Coastguard QP28	15.22	33.88	15.51	33.59	15.81	34.00	16.63	34.07
Mobile QP24	33.35	36.6	33.59	36.65	34.16	36.73	38.02	36.79

It is clear that in both the sequences the bit rate of the up switching is more than that of down switching, due to following two reasons (i) in case of up switching the reference frame is of lower quality than the current frame (PSP), increasing the error signal and hence the bit rate, (ii) this increased error signal is coded with the lower QP (high quality) further increasing the bit rate of the SSP-frame, and vice versa for down switching.

Repeating the experiments for a number of different sequences with different combinations of the QSP and QSSP and ignoring all the values occurring in the grey range, the safe range of the quantization parameters recommended are given as

$$QP - 5 \leq QSP \leq QP - 0$$
$$QP - 0 \leq QSSP \leq QP + 8 \qquad (6)$$

Here it is ensured that the QSSP should work with all the values of the QSP, keeping PSNR as close as possible to that of the P-frames.

4. SIMULATION RESULTS

To validate our findings extensive simulations were carried out with a wide range of quantization parameters and video sequences and it was concluded that there is a very small range of QPs for which the bit rate of both the PSP and the SSP-frames is lower than the bit rate of I-frames at that frame positions. Although there is a grey area where it is difficult to draw a boundary between the QPs generating switching frames with lower bit rate than I-frames for all types of video sequences, but the safe range for QSP and QSSP in (6) is selected very strict in the sense that the grey area is completely omitted, and it is ensured that the range defined will produce switching frames with lower bit rate than I-frames for both up switching and down switching.

The bit rate and the PSNR of PSP and SSP frames coded with the quantization parameters from the given safe range are shown in Tables 1 and 2 respectively. Table 1 shows the average bit rate and PSNR of one GOP for sequence with PSP-frames, I-frames and P-frames. The bitrate of the PSP-frames are compared with that of the I-frames while the PSNR is compared with that of the P-frames.

In all the cases the QSP and QSSP of the PSP-frames are according to the equations given in the first row while for all the remaining P-frames and I-frame the QP is the same as shown in the first column along with the sequence name. It is clear that the bit rate of the PSP-frames is lower than that of the I-frames for all the values. The quality of the PSP-frames is compared with that of the P-frames and it is clear that quality is nearly equal to that of P-frames.

Table 2 shows the comparison of the average bit rate of the GOP having SSP-frames with the average bit rate of the GOP having I-frames. The values given next to the sequence names are the QP values showing switching from the first value to the second value (first QP – second QP). It can be seen that in all the cases the bit rate of the SSP-frame is lower than the I-frames, supporting our safe range of the quantization parameters. Here the PSNR is not compared as SSP-frame is the exact reconstruction of the PSP-frame and the PSNR remains same as in Table 1.

Thus it is experimentally verified that selecting the QSP and QSSP for the switching frames from the safe range will result in efficient coding of switching frames as compared to I-frames and

Table2: Comparisons of SSP and I-frames for various combinations of QSP and QSSP

Sequence	QSP=QP-1 QSSP=QP	QSP=QP-2 QSSP=QP	QSP=QP-3 QSSP=QP	I-frames
	Rate (bits)	Rate (bits)	Rate (bits)	Rate (bits)
Foreman (20-28)	7038	6960	6950	7324
Akiyo (32-28)	2820	2830	2854	3112
Coastguard (32-24)	28004	28116	28238	28298
Mobile (20-32)	12420	12339	12093	13131

the quality will also be very close to that of the P-frames along with reliable transmission on bandwidth limited channels, increasing QoS.

5. CONCLUSION

Switching frames are designed for drift free reconstruction even from a different reference frame, with better coding efficiency than the I-frames. To enable this drift free reconstruction from different reference frames these frames are quantized twice. This results in a decreased quality as compared to other motion compensated P-frames due to extra quantization errors. To compensate for these quantization errors the quantization parameters are usually taken less than that of the rest of the sequence, increasing the bit rate, some times even exceeding that of I-frames. The main question which was studied and answered in this paper was up to what values decrease in these quantization parameters can be allowed so that the bit rate does not exceed that of I-frames?

The PSNR and the bit rate of the switching frames were compared with those of P and I-frames respectively, and it is shown that for a large range of quantization parameters the bit rate of the switching frames exceeds that of I-frames making them practically inefficient especially when the bandwidth is limited as in case of mobile communication. With extensive simulations a safe range of quantization parameters is recommended for switching frames, such that their bit rate is maintained lower than those of the I-frames and PSNR close to that of the P-frames. Simulation results show that using our recommendations of the quantization parameters will not only ensure lower bit rate of switching frames as compared to I-frames, but will also decrease the number of packets and hence the delay.

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