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Analysis and evaluation for the Scalability Mechanisms of H.264/SVC

***Abstract**. Compared with the scalable parts of previous video coding specifications, the Scalable Video Coding (SVC) extension of H.264 Advanced Video Coding (AVC) standard (short for H.264/SVC) has demonstrated significant improvement of video compression performance. In this paper, different coding methods for scalability are analyzed and their influence on the performance of H.264/SVC is investigated through extensive experiments. The conclusions derived from experimental results would serve as solid bases for the future improvement of encoder design.*

***Streszczenie.** W porównaniu z wcześniejszymi metodami kodowania sygnału video rozszerzenie SVC (Scalable Video Coding) znane jako standard H.264/SVC wykazuje znaczą poprawę jakości kompresji. W artykule analizowano i porównano różne eksperymentalnie metody kodowania. (**Analiza i ocena metody kodowania sygnału video H.264/SVC**)*

Keywords: temporal scalability; spatial scalability; quality scalability; H.264/SVC
Słowa kluczowe: kodowanie video, kompresja, H264.

1 Introduction

The modern communication systems present several new characteristics, such as heterogeneous network, time-varying bandwidth, and various terminal equipments, which promote the challenge to video coding technology. With the desire for meeting these challenges, the scalable video coding has become the research focus of video coding for several years and the effort for standardizing it produced the newest scalable video coding standard, i.e. H.264/SVC, in 2007 [1]. Based on the excellent coding performance of H.264/AVC and several new coding tools, H.264/SVC outperforms all the scalable parts of previous video coding standards and can be the promising specification deployed extensively into the practical commercial applications.

Although the Joint Video Team (JVT) has discussed some other scalability mechanisms [2,3], H.264/SVC mainly supports three kinds of scalabilities, i.e. temporal scalability, spatial scalability and quality scalability, at present. With the only change of the signalling for temporal layers, the temporal scalability is implemented by the concept of hierarchical B-frame prediction structure, which is already supported by H.264/AVC. The realization of spatial scalability depends on the traditional multilayer coding scheme and the inter-layer prediction methods are employed to exploit the statistical dependencies between different layers for improving the coding performance of H.264/SVC encoder. The quality scalability includes Coarse Grain Scalability (CGS) and Medium Grain Scalability (MGS), whose base layer and enhancement layer are encoded with similar mechanisms to spatial scalability in same spatial resolution.

For a common base of standard discussion, the JVT developed a reference software model, i.e. Joint Software Video Model (JSVM) [4]. As in Fig. 1, JSVM employs multi-layer coding structure to achieve the scalability mechanisms of H.264/SVC. In each layer, the temporal scalability is implemented by the hierarchical B-frame structure as usual inter-frame coding with two reference frames in H.264/AVC and temporal layers are identified by the temporal identifier *TId* (*TId* ≥ 0). Every spatial layer corresponding to a spatial resolution is called as dependency layer which is identified by a dependency identifier *DId* (*DId* ≥ 0). If the spatial resolutions of several layers are identical, this special case of spatial scalability is called as CGS. With the inter-layer prediction methods, CGS is similar to spatial scalability but without the up-sampling operations and inter-layer de-blocking for intra-coded reference layer macro-blocks and the transform coefficients of the reference layer need to be used as the reference for the transform coefficients of enhancement layer. The main difference between CGS and MGS is the modified high-level signalling, which supports the key picture concept and the coefficients partitioning mechanism of MGS. MGS encoding is performed in a spatial layer and every MGS layer is identified by a quality identifier *QId* (*QId* ≥ 0).

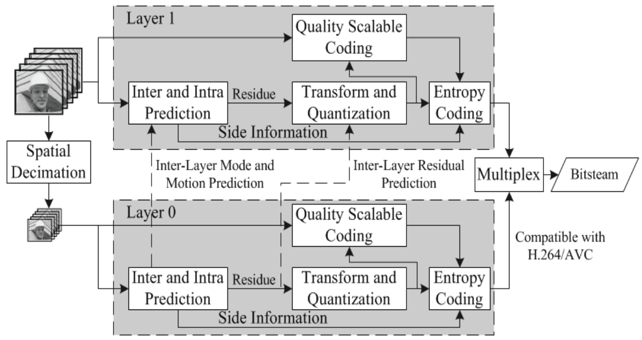

Fig.1. The multilayer structure of JSVM

Although the complex coding structure of Fig.1 is widely discussed, how to improve its performance is still an open problem. Many methods have been developed to improve the encoder performance. This paper mainly investigates the influence of different methods on the rate-distortion (R-D) performance of JSVM, which is evaluated by the R-D curve. Herein, R represents the kilo bit per second (kbps) and D is calculated by the weighting Peak Signal to Noise Ratio (PSNR) of the three components of Y, Cb, Cr in a video frame as follows

$$PSNR = \frac{4 \times YPSNR + CbPSNR + CrPSNR}{6} . \quad (1)$$

And its unit is dB. Under an encoding parameter, encoder produces a pair of (R, D) value. Finally, the R-D curve is defined by these (R, D) points. The higher R-D curve means that it corresponds to an encoder or coding method with higher coding performance and ΔPSNR can be calculated by the method of [5] using the points of two R-D curves to denote the performance improvement.

The rest of this paper is organized as follows. First, the characteristic of bit allocation in the temporal scalability is discussed and different cascading QP schemes are tested. Then the different inter-layer mechanisms and multi-layer control structure are tested for the spatial scalability. Third, the extraction performance is demonstrated for quality scalability. Finally, the conclusion is made for this paper.

2 Cascading QP for temporal scalability

Essentially, the temporal scalability of hierarchical B-frame coding structure provides several available choices of frame rate in a single scalable video bit-stream for potential users. As in Fig. 2, I frame or P frame is encoded as key picture, which corresponds to the smallest frame rate and is identified by *TId* = 0. B frames with *TId* ≥ 1 are inserted into the interval between two adjacent key pictures to increase the frame rate. The frame rate is doubled after the number of temporal layers is increased by 1. B frames between two successive key pictures together with the succeeding key frame constitute a group of pictures (GOP). In principle, the frames with lower *TId* should be encoded with better quality because their reconstruction data would be referred during the motion compensation of B frames with *TId* ≥ 1 and the total coding efficiency would be significantly improved if more bits are allocated to the encoding of lower temporal layers. This bit allocation strategy can be realized by cascading the value of quantization parameter (QP) for different temporal layers [6].

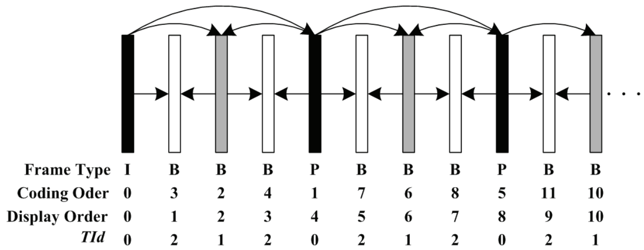

Fig. 2. Hierarchical B frames structure with GOP = 4

In cascading QP methods, frames with smaller *TId* use smaller QPs and frames with the same *TId* are encoded with the same QP. There are two kinds of cascading QP methods. One is recommended by the proposal of Heinrich Hertz Institute (HHI) [6] in JVT conference. Let QP(*i*) denote the QP of temporal level with *TId* of *i*. The QPs for frames in different temporal level are calculated as

(2) $$\mathrm{QP}(i) = \mathrm{QP}(0) + \Delta\mathrm{QP} + i,\ i = 0,1,2,\ldots,$$

where ΔQP is the increment of QP from the temporal base layer to the temporal level with *TId* of 1. In this paper, a special case of (2) is used in our experiment as

(3) $$\mathrm{QP}(i) = \begin{cases} \mathrm{QP}_{ref} - 2 + i,\ i = 0 \\ \mathrm{QP}_{ref} + 0 + i,\ i \geq 1 \end{cases},$$

where $\mathrm{QP}_{\mathrm{ref}}$ is a reference QP input as encoder parameter. In our experiments, this method is denoted as "CasQPHHI". The other cascading QP method is derived from the video coding based on wavelet [7] and calculates a scaling factor to determine the difference between the QP of temporal level with *TId* of *i* and $\mathrm{QP}_{\mathrm{ref}}$, i.e. ΔQP. Consequently, the QP for the i^{th} frame of a GOP can be decided as follows

(4) $$\begin{cases} \mathrm{QP}(i) = \mathrm{QP}_{ref} + \Delta\mathrm{QP} \\ \Delta\mathrm{QP} = -6.0 \times \log_2 SF(i) \end{cases},$$

where *SF*(*i*) is the scaling factor of the i^{th} frame and its calculation is based on the filters used and the number of connected samples in the motion compensated prediction [8]. The detailed calculation of *SF*(*i*) can be referred in [9]. In our experiments this method is denoted as "CasQPSF". To build a test benchmark, firstly, in our experiments, the same QP was used to encode all the frames of a video sequence and this coding method is called as "SameQP".

Our experiments are carried out with the control of Rate Distortion Optimization (RDO) turned on. At first, the results of above three QP setting strategies are given in Figure 3 and Table 1. "CasQPSF" and "CasQPHHI" can improve the R-D performance significantly relative to "SameQP". For the sequences with low motions or simple spatial contents (e.g. city and mobile), "CasQPSF" and "CasQPHHI" can achieve higher performance than sequences with high motions or complicated spatial contents (e.g. football and soccer).

Then, we compare the performance improvement when the size of GOP increases from 1 to 2, 2 to 4, 4 to 8 and 8 to 16 as in Fig. 4. We can observe that the relative increase of coding performance declines with the increase of GOP size. And the performance difference between "CasQPSF" and "CasQPHHI" is smaller when GOP size is small than when GOP size becomes large.

Table 1. Performance improvement of Cascading QP

GOPSize	Sequence	CasQPHHI vs. SameQP (dB)	CasQPSF vs. SameQP(dB)
16	bus	0.68886	0.860619
	city	0.936851	1.131347
	crew	0.374847	0.387884
8	football	0.280332	0.293718
	foreman	0.758265	0.868799
	harbour	0.712181	0.779196
4	ice	0.415214	0.422656
	mobile	0.723183	0.779502
	soccer	0.346217	0.329352

We can derive some conclusions on the basis of above experimental results. Firstly, the coding performance would be further improved if the QP setting strategy is fit for the encoding of GOP. In above three methods, "CasQPSF" is based on the filters and the motion compensated prediction of GOP, and "CasQPHHI" only sets the cascading QPs manually. Obviously, "CasQPSF" is the best candidate for QP setting of temporal scalability in above three methods and this point is verified by the results of experiments. On the other hand, although the cascading QP method can improve the coding performance indeed, the difference of QP between adjacent temporal levels should be calculated carefully to ensure enough bits to be allocated to B frames.

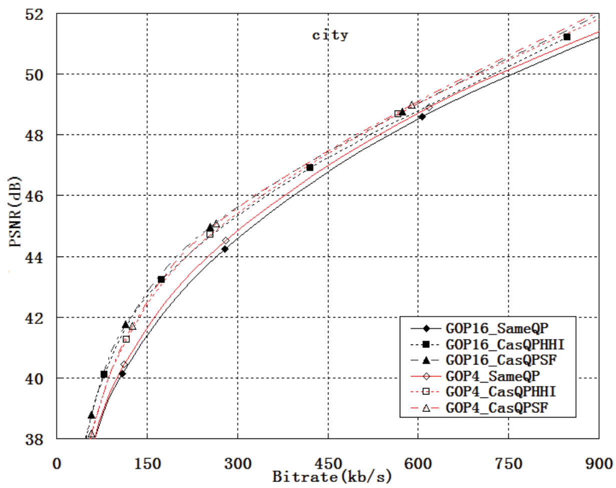

Fig.3. Comparisons of three QP settings with GOP size of 16 and 4 for temporal scalability

Second, the coding performance improvement brought from the increase of GOP size is smaller and smaller when GOP size becomes larger and larger. The GOP size of 8 or

16 should be the most suitable GOP size, because they can not only provide greater performance gain, but also ensure enough ability for temporal scalability. Nevertheless, the problem that the best GOP size is 8 or 16 is video content dependent. The most perfect scheme is that the GOP size is adaptive to the characteristics of the video sequence.

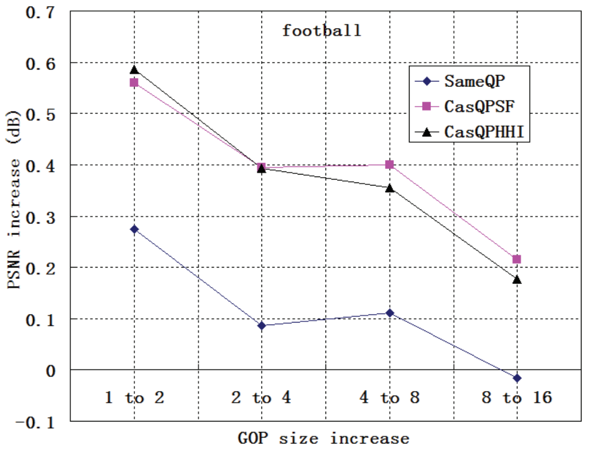

Fig.4. GOP size increase vs. PSNR increase

3 Inter-layer prediction and encoder control for spatial scalability

The target of the spatial scalability is to support several spatial resolutions in one bit-stream. This target requires the multiplexing of several bit-streams with different spatial resolutions as in Fig. 1. This multiplex method is similar to the video simulcast. Accordingly, the spatial scalability has to provide better performance than simulcast using some other encoding methods. Without considering the temporal scalability in each spatial layer, the encoding structure of spatial scalability can be simplified as in Fig. 5. In each spatial layer, video frames are encoded as in single layer coding. It means that motion compensation and intra-prediction are employed as usual. However, the inter-layer prediction mechanisms are incorporated into the procedure of the RDO mode selection to exploit the potential of using the inter-layer redundancy.

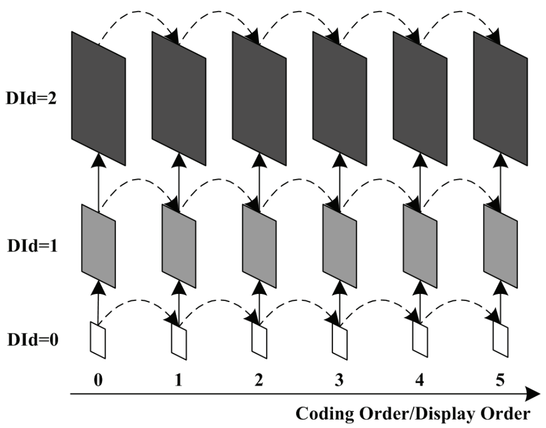

Fig.5. Encoding structure of spatial scalability without B frame

According to the draft of H.264/SVC standard in 2007 [10], the inter-layer prediction mechanisms include three kinds of methods, i.e. inter-layer motion prediction, inter-layer residual prediction and inter-layer intra-prediction. On the basis of the syntax element called *base_mode_flag*, the inter-layer motion prediction can be realized from two ways. When *base_mode_flag* is equal to 1 and the corresponding 8x8 block in reference layer is inter-frame coded, the block partition, reference index and motion vectors of current layer can be derived from these information of 8x8 block in reference layer. That is, in current layer, the block partition is the up-sampled result of 8x8 block in reference layer; reference index is copied from reference layer; and motion vector is the scaled version of reference layer motion vector. When *base_mode_flag* is equal to 0 and another syntax element *motion_prediction_flag* is 1, reference index and motion vector prediction is derived from reference layer. Then, inter-layer residual prediction is based on a syntax element *residual_prediction_flag*. When this flag is 1 and current macroblock is inter-coded, the residual of reference layer is up-sampled and treated as the predictor of current layer residual. The inter-layer intra-prediction is similar to inter-layer motion prediction, but the reference layer 8x8 is intra-coded and the reconstructed reference layer data is up-sampled to be the prediction signal of current layer.

Table 2. Performance improvement comparison of various combinations of inter-layer prediction mechanisms

Combinations	ΔPSNR relative to simulcast (dB)		
	crew	foreman	harbour
(Mod, Res, Mot)	0.9740704	0.7243986	0.2522947
(Mod, Res)	0.9385491	0.6945668	0.2521571
(Mod, Mot)	0.3900695	0.3283565	0.0455878
(Res, Mot)	0.6192996	0.5103683	0.2095992
(Res)	0.4457091	0.3137045	0.2161324
(Mod)	0.3674067	0.3094925	0.047774
(Mot)	0.1064086	0.1471677	-0.007374

From above statement, we can see these mechanisms are a little complicated. For simplicity, in the newest version of JSVM, i.e. JSVM 9.19, using some small changes, above three mechanisms is transferred to another three, i.e. inter-layer mode prediction, inter-layer residual prediction and inter-layer motion prediction, respectively denoted as 'Mod', 'Res', and 'Mot'. The inter-layer mode prediction is actually the combination of above 2007 inter-layer motion prediction and inter-layer intra-prediction with the syntax element *base_mode_flag* is equal to 1. The inter-layer residual prediction is same to the 2007 version. Whereas, the inter-layer motion prediction is actually the 2007 inter-layer motion prediction with *base_mode_flag* is equal to 0 and *motion_prediction_flag* is 1.

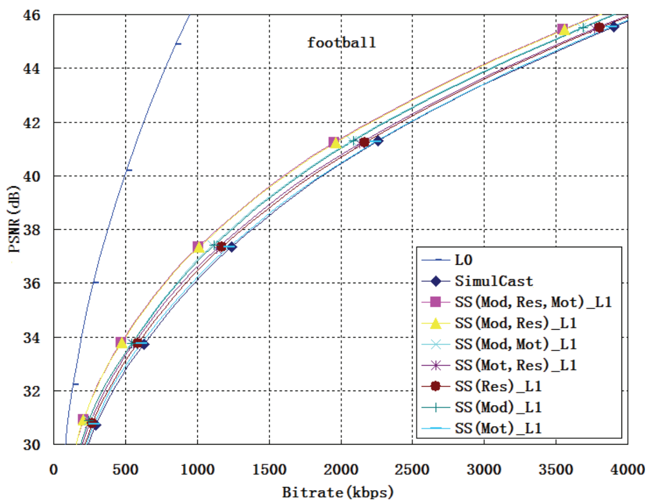

Fig.6. Performance comparisons for spatial scalability (SS) with different combinations of the inter-layer mechanisms

The inter-layer prediction mechanisms are important coding tools for spatial scalability. To investigate the effect of different inter-layer prediction mechanisms on encoder performance, spatial scalability experiments with two layers encoding structure similar to Fig. 5 are performed with the RDO turned on and various combinations of inter-layer prediction mechanisms. The performance of simulcast is used as the benchmark of PSNR comparison.

Results are presented in Fig. 6 and Table 2. The curve “L0” represents the performance of Layer 0 with image size of 176×144 and other curves are the performance curves of Layer 1 with image size of 352×288. If only one in above three mechanisms is chosen, we can find that SS(Mot)_L1 brings the least improvement. And if two of above three is chosen, SS(Mod, Res)_L1 is the best. Finally, SS(Mod, Res, Mot)_L1 can result in the best improvement in above seven combinations.

Another important technology point for spatial scalability is the method for encoder control. The problem of encoder control is the most basic problem for video coding, which can be treated as an optimization problem. That is to say, this problem is the research of how to control the encoding process to achieve the best performance with bits number as least as possible. This kind of optimization problem can be solved by several methods and the most practical method is the widely-used Lagrangian scheme [11]. The Lagrangian encoder control scheme has been deeply researched for the single layer coding and needs some changes for multilayer coding structure of spatial scalability.

JSVM employs a bottom-up encoding process, in which the spatial layers with smaller *DId* are encoded before those with larger *DId*. Due to the inter-layer prediction methods, the coding of base layer would affect the coding efficiency of enhancement layers. Consequently, the impact of base layer on enhancement layers must be considered and the encoding of all layers should be jointly optimized to achieve the best overall coding efficiency. As in [12], the process of RDO should be extended as follows

(5) $$\min\{J\} = \min\{(1-\omega)\cdot J_0 + \omega \cdot J_1\},$$

where $\omega \in [0, 1]$ is a layer weighting factor, J_0 and J_1 are the RD cost of the base layer and the enhancement layer. From [11], we know that the key of Lagrangian scheme is the calculation of Lagrange multiplier. After the investigation of the Lagrange multiplier selection for multilayer encoding structure [13], JSVM adopted this proposal as its encoder multilayer control method. According to [13], the multilayer Lagrange multiplier can be computed as

(6) $$\lambda_1 = \frac{\beta \cdot 2^{\Delta QP/6}}{\beta \cdot 2^{\Delta QP/6}+1} \times \lambda_0$$

where ΔQP is the difference between the QPs for base layer and enhancement layer, λ_0 is the Lagrange multiplier of base layer, and β is the resolution ratio between base layer and enhancement layer.

Table 3. Performance improvement comparison of the multi-layer control and multi-loop encoding

Configuration	ΔPSNR relative to simulcast (dB)			
	football	foreman	ice	soccer
SLP_SLC	1.24355	0.72439	0.60322	0.61961
SLP_MLC	1.33519	0.83951	0.78897	0.72813
MLP_SLC	1.22717	0.71505	0.61953	0.62276
MLP_MLC	1.32667	0.83332	0.77554	0.71468

Experiments are carried out with the multilayer control on (MLC) and off (SLC) and with three inter-layer prediction mechanisms chosen adaptively. And though H.264/SVC is designed with single-coding loop (SLP), we can carry out the multi-loop encoding (MLP) and its performance can be treated as a comparison with others. The performance of video simulcast is also used as the test benchmark of PSNR comparison.

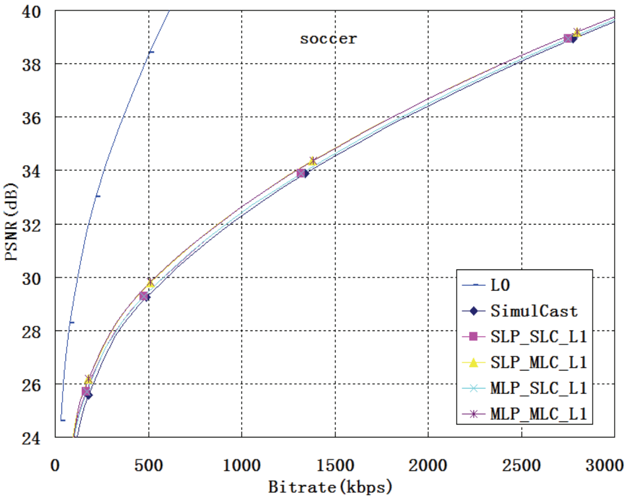

Fig.7. Performance comparisons for spatial scalability (SS) about the multi-layer control and multi-loop encoding

Results are presented in Table 3 and Fig. 7, from which SLP_MLC and MLP_MLC can achieve PSNR improvement relative to SLP_SLC and MLP_SLC respectively, however, the improvement of MLP_SLC and MLP_MLC is very small relative to SLP_SLC and MLP_SLC respectively.

From above experimental results, we can achieve some conclusions for spatial scalability. Firstly, the performance improvement of spatial scalability is very obvious relative to SimulCast. This is the contribution of inter-layer prediction mechanisms with acceptable increase of computational complexity. Secondly, in these three inter-layer prediction mechanisms, the improvement from the inter-layer motion prediction is the smallest. That is because additional bits are needed to transfer the data of Motion Vector Prediction in enhancement layer. Thirdly, the improvement from the multi-layer encoder control is better than that from multi-loop encoding. This is because the amount of Intra-coding block is small relative to that of Inter-coding block. Thereby, the multi-loop encoding based on the Intra-coding can not improve the performance further.

4 Bit-stream extraction for quality scalability

The quality scalability satisfies the need of improving the subjective perceive at fixed spatial and temporal resolution and is always the most important scalability mechanism from previous standards to current H.264/SVC. Similar to the quality scalability in MPEG-2, CGS is achieved based on the successive finer quantization of residual. Due to the dependency of motion compensation in each CGS layer, the bit rate switching between CGS layers only takes place at some encoding start points, i.e. Instantaneous Decoding Refresh (IDR) pictures. This requirement limits the video adaptation granularity of CGS and promotes the produce of MGS. In the initial phase of H.264/SVC development, the fine granular quality scalability (FGS) was the first candidate for the quality scalability. However, from experiments MGS can provide similar results to FGS with simple concepts and significantly reduced computational complexity. Hence, MGS was adopted by JVT. Compared with CGS, the finer granularity of MGS is supported by the concept of key picture and the coefficients partitioning mechanism. The concept of key picture is employed to restrict the drift within the range of GOP with an acceptable complexity. And the coefficients partitioning mechanism uses the concept of frequency scalability to increase the rate switching points of MGS essentially. The detail of these two mechanisms can be found in [1].

Based on the quality scalability, video adaptation can be implemented by bit-stream extraction technology, which is to extract some parts of bit-stream and abandon other parts of bit-stream to meet the need of channel bandwidth or the constraint of store capability. Bit-stream extraction needs some information about bit-stream to decide whether a video data packet is reserved or abandoned. At present, there exist two kinds of information. One is based on the basic scalability information, namely scalability identifier (dependency_id, temporal_id, quality_id), which is short for (*DId*, *TId*, *QId*), carried in NALU header; the other one employs the rate distortion characteristic of NALU. Based on these two kinds of information, there exist two kinds of extraction methods, i.e. basic extraction and R-D optimized extraction. The former is according to the data of (*DId*, *TId*, *QId*) and the latter uses the R-D characteristic of encoded data. The R-D characteristic are calculated in advance, organized by the concept of quality layer and stored in the priority_id of NALU header or the supplemental enhanced information (SEI) message.

The JSVM is performed to carry out some extraction experiments for MGS with basic extraction (MGSBscExt) and R-D based extraction (MGSRDExt), and for two layers CGS with basic extraction (CGSBscExt). From Fig. 8, It can be found that MGSRDExt outperforms MGSBscExt with higher R-D curve and more extraction points due to its consideration for the video data characteristic. Moreover, CGSBscExt can only provide two extraction points with much weaker extraction performance.

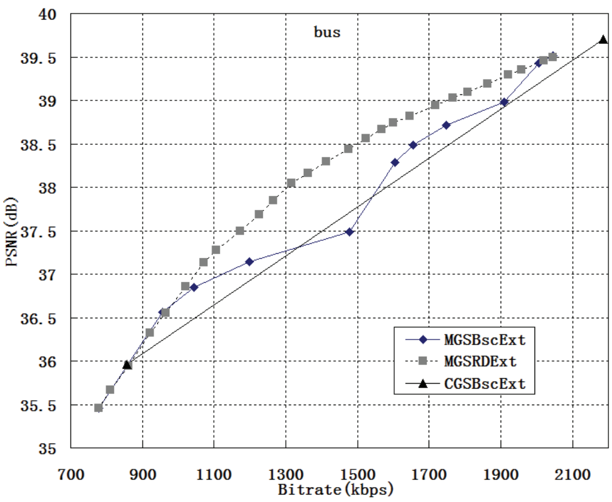

Fig.8. Performance comparisons between MGS and CGS

5 Conclusions

In this paper, the scalability mechanisms of H.264/SVC are analyzed and evaluated. For the temporal scalability, the cascading QP setting scheme can provides profound improvement for coding efficiency. For the spatial scalability, significant improvement is illustrated relative to simulcast and multi-layer encoder control method presents impressive performance increase. For the quality scalability, upcoming R-D optimized extraction would make the lightweight video adaptation become true. In conclusion, H.264/SVC is an excellent specification for scalable video coding and expected to be further enhanced in further research and widely deployed in various business applications.

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