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SPLICED VIDEO AND BUFFERING CONSIDERATIONS FOR TUNE-IN TIME MINIMIZATION IN DVB-H FOR MOBILE TV

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ABSTRACT

A novel video splicing method is proposed which minimizes the tune-in time of mobile TV in Digital Video Broadcasting for Handheld terminals (DVB-H). DVB-H uses a time-sliced transmission scheme to reduce the power consumption used for radio reception. Tune-in time in DVB-H refers to the time between the start of the reception of a broadcast signal and the start of the media rendering. One of the significant factors in tune-in time is the time from the start of media decoding to the start of correct output from decoder, which can be minimized when a time-slice is started with a random access point picture such as an independent decoding refresh (IDR) picture in H.264/AVC. In IP datacasting (IPDC) over DVB-H, the encapsulation to time-slices is performed independently from encoding in a network element called IP encapsulator. At the time encoding, time-slice boundaries are not known exactly, and it is impossible to govern the location of IDR pictures relative to time-slice boundaries. It is proposed that an additional stream consisting of IDR pictures only is transmitted to the IP encapsulator, which replaces pictures in a normal bitstream with IDR pictures according to time-slice boundaries in order to achieve the minimum tune-in time. It has to be ensured that the "spliced" stream resulting from the operation of the IP encapsulator complies with the Hypothetical Reference Decoder (HRD) specification of H.264/AVC. The buffering requirements of spliced stream are analyzed and then a video rate control system is proposed to satisfy the HRD requirements for the spliced stream. Simulation results show that in addition to fulfilling HRD compliancy, good average quality of decoded video is achieved with minimum tune-in time.

I. INTRODUCTION

DVB-H is an ETSI standard specification for bringing broadcast services to battery-powered handheld receivers [1]. DVB-H is largely based on the successful DVB-T specification for digital terrestrial television, adding to it a number of features designed to take account of the limited battery life of small handheld devices, and the particular environments in which such receivers must operate.

In a conventional IPDC system over DVB-H, a content encoder receives source signal and encodes the source signal into a coded media bit stream. The coded media bit stream is transferred to a server. The server is typically a normal IP multicast server using real-time media transport over RTP. The server encapsulates the coded media bit stream into RTP packets. The server is connected to an IP Multi-Protocol Encapsulator. The IP encapsulator encapsulates IP packets into Multi-Protocol Encapsulation (MPE) Sections which are further packetized into MPEG-2 Transport Stream packets. The IP encapsulator optionally uses MPE Forward Error Correction (MPE-FEC) based on Reed-Solomon codes. An IPDC system over DVB-H further includes a radio transmitter which is not essential for the operation of the proposed splicing system and it is not discussed further.

To reduce the power consumption in handheld terminals, the service data is time-sliced and then it is sent into the channel as bursts at a significantly higher bit rate compared to the bitrate of the audio-visual service. Time-slicing enables a receiver to stay active only a fraction of the time, while receiving bursts of a requested service. Finally, the system includes one or more recipients, typically capable of receiving, demodulating, decapsulating, decoding, and rendering the transmitted signal, resulting into uncompressed media stream.

The tune-in time or delay for newly-joined recipients consists of several parts including: delay until the start of the desired time-slice, reception duration of a complete time-slice or burst, delay to compensate the variation in size of bursts and video frames, delay to compensate the synchronization between the associated streams of the streaming session and delay until a media decoder is refreshed by a random access point. One of the critical factors in tune-in time is the time until a media decoder is refreshed to produce correct output, which can be minimized if time-slice is started with a random access point such as an IDR picture in H.264/AVC. It should be remarked that if the decoder started decoding from an IDR picture that is not at the beginning of a time-slice immediately when the time-slice is received, the input buffer for decoding would drain before the arrival of the next time-slice and there would be a gap in video playback.

In IPDC over DVB-H, the content encoding and the encapsulation to MPE-FEC frames are implemented independently and it is hard to govern the exact location of IDR pictures relative to the boundaries of MPE-FEC frames. Moreover, very frequent IDR pictures in the bitstream drops the compression efficiency remarkably.

In our previous work [2], we proposed a video splicing method, which minimizes the decoder refresh time in IPDC over DVB-H without any increase in bandwidth and modification on the receiver. In this paper after a short review of the proposed splicing method we analyze the buffering requirements of proposed spliced bit stream and then a general video rate control system is proposed to ensure the HRD compliancy of the spliced bitstream. Proposed splicing method is reviewed in section II of this paper. Section III and IV presents HRD buffering considerations and details of proposed rate control system respectively. Simulation results are presented in Section V. The paper closes with conclusions in section VI.

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II. PROPOSED SPLICING METHOD

A simplified block diagram of the proposed IPDC system is depicted in Figure 1. At the content encoding level one or two video encoders encode the uncompressed input video to two encoded primary bit streams including a Spliceable Bit Stream (SBS) and a decoder refresh bit stream (DRBS) from the same source picture sequence. The SBS includes very frequent spliceable pictures which are reference pictures constrained as follows: no picture prior to a spliceable picture, in decoding order, is referred to in the inter prediction process of any reference picture at or after the spliceable picture, in decoding order. Non-reference pictures after the spliceable picture may refer to pictures earlier to the spliceable picture in decoding order. These non-reference pictures cannot be correctly decoded if the decoding process starts from the spliceable picture, but can be safely omitted as they are not used as reference for any other pictures. The DRBS is containing only IDR pictures corresponding to spliceable pictures and with a picture quality similar to corresponding spliceable pictures. The DRBS and the SBS are transmitted from the server to the IP encapsulator. The IP encapsulator composes MPE-FEC frames, in which the first picture in decoding order is an IDR picture from the DRBS and the other pictures are from the SBS. The IDR pictures at the beginning of MPE-FEC frames minimize the tune-in time for newly-joined recipients. No changes in the receiver operation are required in the proposed system.

Replacing an inter picture with an intra picture in the SBS causes a mismatch in the pixel values of the reference pictures between the encoder and decoder. The mismatch propagates temporally an error until the next IDR picture in the spliced stream. A technically elegant solution would be to use SP and SI pictures of H.264/AVC, but they are only included in the Extended profile of H.264/AVC [3]. The Extended profile of H.264/AVC is not allowed in the current DVB-H standard [4]. A similar solution was proposed for stream switching in streaming servers by Farber and Girod in [5]. They used a kind of S-frame more specifically, to enable switching between bit streams. Unlike SP pictures in [3], S-frames introduce mismatch error while switching between bit streams. To minimize mismatch error, the quantization parameter used for S-frames should be kept small. While in our application we do not need to switch between multiple bit streams, instead of high quality switching frames, the spliceable pictures and corresponding IDR pictures can be encoded with a higher quality than other pictures to decrease the mismatch error.

Experimental results of proposed splicing method show that the propagated error is saturated to a constant relative small value after several frames. Moreover visual quality tests show that the error is perceivable hardly visible.

The error propagation degrades the quality of reconstructed video by spliced stream in comparison to SBS. Moreover the quality of decoded SBS is degraded due to the proposed constraint on the reference frames. However, the resulting degradation in quality can be small compared to a conventional system in which very frequent IDR frames in a normal bit stream degrade the average quality by consuming more bit budget and still it can not minimize the tune-in delay. Moreover, simulation results show that the employment of spliceable pictures and corresponding IDR pictures with a higher quality than other pictures decreases the mismatch error remarkably.

III. HRD BUFFERING CONSIDERATIONS

According to the proposed splicing method the spliceable pictures and corresponding IDR pictures in two primary streams should be encoded with similar qualities. In a similar quality an IDR frame can consume a bit budget from 5 to 10 times more than corresponding inter picture. Furthermore, similar qualities for corresponding frames in two primary streams means that only the bit rate of one primary stream can be controlled. Consequently, there is no real short term control on the bit rate of splice streams and thereafter it is hard to verify the HRD compliancy of spliced stream. Moreover the encoding parameters can not be controlled according to the results of splicing where the encoding and splicing are implemented independently and without any feedback link.

In this section we try to estimate the buffering requirements for the spliced bit stream according to the buffering constraint which is used for the encoding primary streams. First a buffering model for the content encoder is presented which is a simplified version of HRD coded picture buffer (HRD-CPB) model in H.264/AVC. Then we assume that the proposed buffering model is used for the rate control of spliceable bit stream and try to extract the buffering requirements for the buffering of spliced stream. Finally we propose a rate control mechanism for implementation of video splicing to provide the HRD compliancy of the spliced bit stream and to keep the buffering requirements in the standard range.

A. Buffering Model

The following buffer model is considered as a simplified version of HRD-CPB model. The buffer fullness is updated after encoding each picture as:

$$B(i) = B(i-1) + TB/TF - P_i, \quad (1)$$

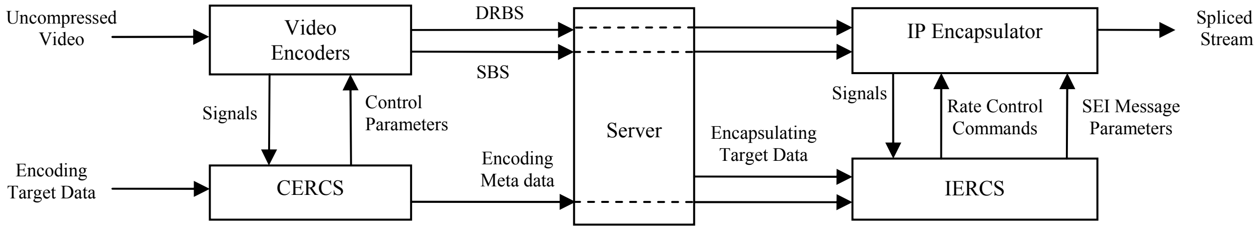

Figure 1: Block diagram of proposed splicing and rate control system

where $B(i)$ refers to the buffer fullness after encoding *i*th picture. TB and TF denote the target bitrate and frame rate respectively. P_i indicates the bit budget consumed by the *i*th picture. In a period of time with initial buffer fullness (B_0), after encoding a number of N pictures from the spliceable bit stream, the buffer fullness is:

$$B_P(N) = B_0 + N\frac{TB}{FR} - \sum_{i=1}^{N} P_i, \quad (2)$$

where B_P denotes the buffer fullness for the SBS. If the whole bit stream with M pictures comply the target bitrate, the buffer fullness above can be represented as:

$$B_P(N) = B_0 + \frac{N}{M}\sum_{j=1}^{M} P_j - \sum_{i=1}^{N} P_i. \quad (3)$$

Now we try to estimate the buffering requirements for the spliced bit stream.

B. Buffering Requirements for Spliced Stream

Consider a spliceable bit stream with a total number of M pictures is spliced such that it forms a number of m MPE-FEC frames and in a simple case, each MPE-FEC frames includes p pictures i.e. $M = p \times m$. Using the buffering model above for the spliced stream, with the same initial buffer fullness (B_0), after decoding a number of $N = p \times R$ pictures, the buffer fullness is:

$$B_S(N) = B_0 + N\frac{TB_S}{FR} - \sum_{i=1}^{N} P_i - \sum_{j=1}^{R}(I_j - P_j), \quad (4)$$

where P_j denotes the replaced spliceable picture by the IDR picture I_j. TB_S refers to the target bitrate of spliced stream and it can be computed as:

$$TB_S = \frac{FR}{M}\left(\sum_{i=1}^{M} P_i + \sum_{j=1}^{m}(I_j - P_j)\right). \quad (5)$$

Replacing TB_S in the formula (4) results:

$$B_S(N) = B_0 + \frac{N}{M}\left(\sum_{i=1}^{M} P_i + \sum_{j=1}^{m}(I_j - P_j)\right) - \sum_{i=1}^{N} P_i - \sum_{j=1}^{R}(I_j - P_j). \quad (6)$$

Considering the buffer fullness for the spliceable bit stream in (3) we can proceed as:

$$B_S(N) = B_P(N) + \frac{N}{M}\sum_{j=1}^{m}(I_j - P_j) - \sum_{j=1}^{R}(I_j - P_j), \quad (7)$$

$$B_S(N) = B_P(N) + R\times\overline{(I_j - P_j)} - \sum_{j=1}^{R}(I_j - P_j), \quad (8)$$

were $\overline{(I_j - P_j)}$ denotes the mean value of $(I_j - P_j)$. For an ideal case if variance of $(I_i - P_i)$ is equal to zero then

$$R\times\overline{(I_j - P_j)} = \sum_{j=1}^{R}(I_j - P_j), \quad (9)$$

thereafter, $B_S(N) = B_P(N)$. In this ideal case a moment (ε) before removing the *R*th IDR frame from the buffer, there is a local maximum in the buffer fullness as:

$$B_S(N-\varepsilon) = B_P(N-\varepsilon) + I_R - P_R, \quad (10)$$

As an important result, this means in ideal case i.e. when the or $Var(I_j - P_j) = 0$, the size of buffer for the spliced bit stream (BS_S) should be larger than buffer size for the spliceable bit stream (BS_P) plus $(I_i - P_i)$ or

$$BS_S \geq BS_P + Max(I_j - P_j). \quad (11)$$

In practice, the variance of $(I_i - P_i)$ can be very far from zero. In this case for a short video sequence with homogeneous content we assume that

$$Abs\left(R\times\overline{(I_j - P_j)} - \sum_{j=1}^{R}(I_j - P_j)\right) = f\left(Var(I_j - P_j)\right), \quad (12)$$

where f indicates a functionality. With a rough linear approximation for the function f, we can proceed as:

$$Abs\left(R\times\overline{(I_j - P_j)} - \sum_{j=1}^{R}(I_j - P_j)\right) = \alpha\times Var(I_j - P_j), \quad (13)$$

where α is a constant coefficient. Using the approximation above and formula (8) it is concluded that

$$B_S(N) = B_P(N) \pm \alpha\times Var(I_j - P_j). \quad (14)$$

Similar to (10) before decoding the *R*th IDR frame

$$B_S(N-\varepsilon) = B_P(N-\varepsilon) + (I_R - P_R) \pm \alpha\times Var(I_j - P_j). \quad (15)$$

Finally the buffer size for the spliced bit stream can be estimated as:

$$BS_S = BS_P + Max(I_j - P_j) + \alpha\times Var(I_j - P_j). \quad (16)$$

Although the formula above can estimate a buffer size in the standard range for a short video sequence with homogeneous content, for a long period of a video sequence with different scene cuts and contents, because of integration on $(I_i - P_i)$ in (12) the required buffer size can be very far from the standard range. To minimize the required buffer size, we propose a rate control system that compensates the long-term variation in $(I_i - P_i)$ results of variation in video content and keeps the required buffer size in the standard range. Utilizing the proposed rate control system make feasible to use the provided results above.

IV. Proposed Rate Control System

To keep the delay and required buffer size for the spliced stream in the standard range a comprehensive rate control system, as shown in Figure 1, is proposed which is implemented in two levels: content encoder level and IP encapsulator level. The content encoding rate control system (CERCS) controls the bit rate of two primary streams according to long-term variation in $(I_i - P_i)$ considering an average value for the frequency of IDR pictures in a desired spliced stream. However the frequency of IDR picture in the spliced stream can have variation around the average value since the number of video pictures in MPE-FEC frame is not fixed. Moreover in offline application the average IDR frequency of spliced stream may be very different from the IDR frequency which has been used for the rate control of primary streams at the content encoder level. This variation in IDR frequency means short-term variation in $(I_i - P_i)$. The IP encapsulator rate control system (IERCS) implements another control to compensate the short-term variation above and to provide HRD compliancy for the spliced stream. Furthermore, the SEI message parameters related to buffering of the spliced stream can be provided by the IERCS.

The CERCS controls the bit rate of primary streams according to encoding target data which are set by user and also according to signals which are extracted from the uncompressed and compressed video. The encoding target data include target bit rate of spliced stream and average frequency of IDR pictures in the desired spliced stream. Some encoding metadata as complementary information are provided by CERCS which are sent to the server and then IP encapsulator. Figure 2 depicts a general block diagram for the proposed CERCS. As it is shown two encoders encodes the DRBS and SBS primary streams from a common input uncompressed video. They use the quantization parameter provided by the video rate controller. Various variable video rate controllers such as our presented controllers in [6] and [7] can be used in this structure. The rate controller utilizes a virtual buffer for the rate control. The virtual buffer is charged by a virtual spliced stream with a constant IDR period and it is discharged with the target bitrate of spliced stream. Primary bit streams and metadata including encoding target data and additional statistics about the encoding results are sent to the server and then to IP encapsulator.

The IERCS at IP encapsulator controls the rate of spliced stream according to the encoding metadata, encapsulating target data defined by the server and several signals which are extracted from the primary streams. The encapsulating target data including target bit rate of spliced stream and IDR frequency of spliced stream are homogeneous with the encoding target date while they may have different values in offline applications.

A HRD-CPB is running at the IERCS which simulates the decoder buffer. IERCS utilizes the HRD-CPB to control the bit rate and also to compute the SEI message parameters related to buffering of the spliced stream. The IERCS controls the bitrate of spliced streams by control of frame rate and type frames. It can drop a number of pictures to decrease the bitrate or it can replace extra spliceable pictures with IDR pictures to increase the bitrate. A perfect IERCS minimizes the number of dropped pictures and prevents unnecessary IDR pictures.

Frome the rate-distortion point of view several points should be considered in implementation of proposed rate control system. First, the size of HRD-CPB which is running at IERCS is equal to size of decoder buffer and they are constraint by the video coding standard. Second, according to formulas (11) and (16) the size of HRD-CPB should be larger than the size of virtual buffer running at the CERCS. A larger HRD-CPB minimizes the number of dropped pictures and the number of extra IDR pictures at the IERCS. On the other hand a larger HRD-CPB increases the delay result of initial buffering period at the decoder. Finally, a larger virtual buffer at the CERCS can increase the quality of compressed video by allowing more variation in the bitrate and a smaller virtual buffer decrease the quality of encoded video by less variation in bitrate and more variation in quality. Therefore, we should find optimum values for the size of virtual buffer and HRD-CPB such that they comply all constraints above and also they maximize the quality of encoded video and minimize the number of dropped-frames. A practical solution for the problem is proposed as follows.

The maximum size of the HRD-CPB may be specified by a video coding standard, e.g. Annex A of the H.264/AVC standard. In the lowest levels of H.264/AVC, the maximum size of HRD-CPB corresponds to approximately 2.5-3 seconds of data at the target bit rate of the level in use. Furthermore, the provided model in (16) expresses the relationship between size of an HRD-CPB and the virtual buffer used by

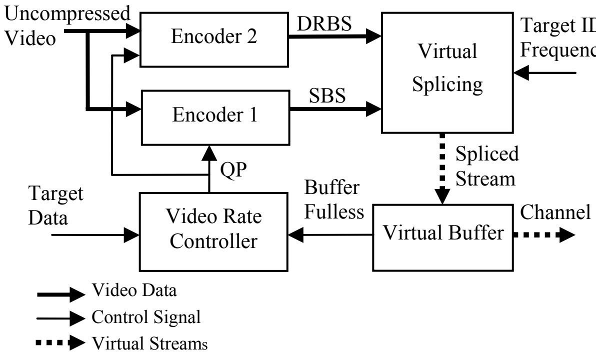

Figure 2: Block diagram of proposed rate control system at the content encoder (CERCS).

the encoder rate controller. In offline applications in which metadata related to mean and variance of $(I_i - P_i)$ are available, using (16) and considering a typical value for α in range of (2-10), the size of HRD-CPB may be calculated as:

$$Size(CBP) = Min(BS_S \text{ , Standard\_Range }) \qquad (17)$$

while the larger α decreases the number of dropped-fames and smaller α decreases the initial buffering delay. In online applications in which prior statistical information is not available, the size of the HRD-CPB may be set in to a desired value at the beginning. Then, using typical values for mean and variance of $(I_i - P_i)$, the size of virtual buffer may be computed as follows. First, the size of HRD-CPB is set to the desired values in standard range as:

$$Size(CPB) = \Delta \times TR \text{, } \Delta \leq 3 \text{,} \qquad (18)$$

using (16) it is concluded:

$$BS_P = Size(CPB) - \overline{(I_i - P_i)} - \alpha \times Var(I_i - P_i) \text{,} \qquad (19)$$

In most video sequences, an IDR frame needs a bit budget about 5 to 10 times more than a P frame encoded with equal quantization scales. Therefore,

$$\overline{(I_i - P_i)} = \Omega \times \overline{P_i} \text{, } \Omega \in [4\_9]$$

as a typical example if we assume that:

$$\alpha \times Var(I_i - P_i) = \overline{P_i}$$

then

$$BS_P = Size(CPB) - \Omega \times \overline{P_i} \text{, } \Omega \in [5\_10]$$

or approximately:

$$BS_P \approx \Delta \times TR - \Omega \times TR / FR \text{, } \Omega \in [5\_10] \text{, } \Delta \leq 3$$

As a numerical example, if $\Delta = 1.5$ and $\Omega = 7.5$ and $FR = 15$, then $BS_P = 1.0 \times TR$.

In offline applications if the IDR frequency used in the CERCS is equal to the average IDR frequency use by the IERCS, the target rate of the spliced stream at the encapsulator is similar to the target rate of the spliced stream at the encoder. Otherwise it may be computed as:

$$TR_2 = TR_1 \frac{F_1}{F_2} \times \frac{BR_P(F_2 - 1) + BR_I}{BR_P(F_1 - 1) + BR_I} \text{,} \qquad (20)$$

where TR_1 and TR_2 denote the target bit rate of the spliced stream at the encoder and the IP encapsulator, respectively. F_1 and F_2 indicate the IDR period used by the CERCS and the IERCS, respectively. BR_P and BR_I denote the average bit rate of the SBS and DRBS streams.

V. Simulation Results

Typical intervals between time-slices containing content for a particular audio-visual service may range from one second to a couple of seconds. If IDR pictures are placed randomly in SBS and the average IDR picture are interval is about equal to the time-slice interval, the expected tune-in time due to decoder refresh is approximately half of the time-slice interval, i.e. typically from half a second to few seconds. From the tune-in time reduction point of view, the proposed splicing method typically decreases the decoder refresh time from to zero or very close to zero.

To study the error propagation in spliced stream, several simulations were run on different video sequences with a lot of different encoding and splicing parameters. In each case we measured the propagated error by several criteria. The results of simulations show that the propagation error is saturated to a constant value after several pictures. The average quality degradation between SBS and spliced bit stream is about 1.6 dB which is almost independent of the frequency of IDR pictures. In another simulation we encoded spliceable pictures and corresponding IDR pictures with a higher quality than other pictures. Moreover, a smaller quantization parameter was used for spliceable pictures than corresponding IDR pictures to get a similar quality. In this case, the average degradation in quality decreased to 1.06 dB. Despite of the drop in PSNR, the subjective impact is hardly noticeable. Furthermore, the degradation in quality of SBS in comparison to a normal unconstrained bit stream is less than 0.1 dB which is insignificant. If we try to minimize the tune-in time in a normal bit stream just by frequent IDR pictures, a penalty much higher than above degradation in quality should be paid. Therefore, the proposed splicing method can be utilized when the use of SP and SI pictures of H.264/AVC is not allowed.

To evaluate the standard HRD compliancy of the proposed spliced bit stream, we encoded 45 minutes of video with 10 different contents to provide the primary streams for spliced streams with different target bit rates, IDR frequencies and frame rates. We concatenated and mixed the known video sequences which are used for the standardization process to provide long video sequences suitable for our simulations. Simulation results show that the proposed rate control system can provide standard compliant bit stream while the location of IDR pictures is not known for encoders. While the size of virtual buffer is only 15% to 20% less than the size of HRD-CPB, a smart IERCS can decrease the percentage of dropped frames to less than 0.3% and the percentage of extra IDR frame to less than 0.1% even if the frequency of IDR pictures in the real spliced stream in encapsulator is very different from the average IRD frequency which is used for the rate control of primary streams by CERCS. The virtual buffer size close to HRD-CPB size means more average quality of compressed video with less initial buffering delay.

Without such rate control system the HRD compliancy of the spliced stream is possible at the expense of a large percentage (20 to 30 times more than provided results) of dropped-frames.

A sample graphical results of buffering simulation in Figure 3 show that how well the final spliced stream in HRD-CPB follows the fullness of virtual buffer at the encoder. Furthermore, it can be seen that the SBS primary stream is not HRD compliant. In fact we control the bitrate of SBS such that the desired spliced stream is standard compliant and there is no need for a HRD compliant SBS. The used video sequence in the experiment above is a mixture of several known video clips including Foreman, Carphone, News, Salesman, Hall, Paris, Container, Silence, Akiyo, New York, Suzie and Sailboat. These results have been provided with no any dropped picture or extra IDR frame at the IERCS.

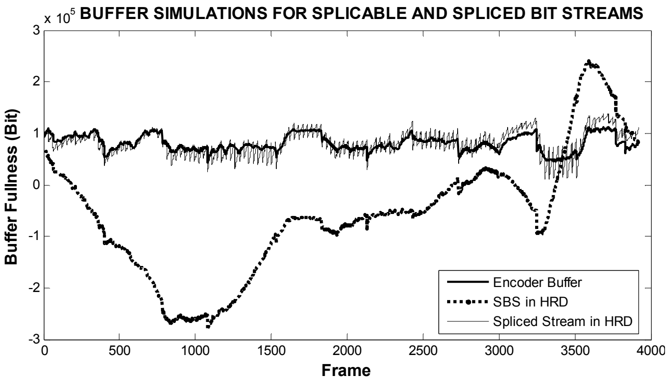

Figure 3: Buffer fullness for the spliceable and spliced bit streams

VI. Conclusion

In this paper we proposed a video splicing method which minimizes the tune-in time in DVB-H for mobile TV. The buffering requirements for the spliced stream were analyzed and a rate control system was proposed to make sure that the proposed spliced bit stream is standard compliance. Provided results show that the proposed splicing method and rate control system can minimize the tune-in time of mobile TV over DVB-H simply at the expense of a relative small degradation in quality of compressed video.

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