A Technical Study on the Transmission of HDR Content over a Broadcast Channel

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Abstract—**High Dynamic Range Television is a topic of current interest in academia and industry since can attribute the same level of realism without the need to increase the resolution. The reference end-to end HDR system is based on HDR10 System due to its encoding efficiency and visual quality. However, it cannot be directed apply for the current Standard Dynamic Range television system. This paper makes a technical study about the system requirements to be considered for transmitting a HDR service in broadcast television and presents objective metrics in different coding scenarios regarding the HDR10 System and a subjective assessment of the generated tone-mapped videos.**

Index Terms—**High Dynamic Range, Broadcasting, Television System.**

I. INTRODUCTION

THE current broadcast television systems still works on 8-bit infrastructure. Each stage of a television system is governed by the traditional television standards. For instance, the BT.709 OETF (Opto-Electrical Transfer Function [1]) converts scene-referred natural images into electrical signals. Likewise, the BT.1886 EOTF (Elecro-Optical Transfer Function [2] converts electrical signals into light. This architecture is known as the "Gamma System".

Today's television systems are known as Standard Dynamic Range (SDR) systems because supports a range of luminance of around 0.1 to 100 nits, about of three orders of magnitude or 10 f-stops. High Dynamic Range(HDR) is defined as any signal or device that has a dynamic range greater than SDR. An Enhanced Dynamic Range (EDR) system covers between 10 f-stops and 16 f-stops and a High Dynamic Range system supports a dynamic range of more than 16 f-stops or five orders of magnitude [3].

HDR proposals are well referenced by International Standard Committees such as the ITU–R Study Group 6 and VCEG/JCT-VC/MPEG. The ITU-R Report 2390 [4] defines the HDR signal parameters for programme production and international programme exchange. There are two proposals widely accepted by the academic and industry community. These are the Hybrid Log-Gamma (HLG), which is a scene-referred signal, and the Perceptual Quantization (PQ), which is a display-referred signal format. The HLG signal is based on a transfer function close to the gamma curve in the range of 0 to 100 nits. After this range, the curve has a logarithmic behaviour. On this basis, this signal is SDR-compatible. Nevertheless, when is displayed the HLG signal into a SDR rendering device, the appearance of distortions, such as color shifting, is noticeable, altering the rendering-intent of the TV producer [5]. The PQ approach proposes a new perceptual uniform coding scheme based on the contrast sensitivity function of the human eye, measured by Barten [6]. This method efficiently encodes the absolute luminance of a real scene in 10 bits [7] with no banding effects. However, the main disadvantage is the non-direct SDR compatibility, since its transfer function does not follow the gamma function. Our previous work ([8] and [9]) proposed the use of a altered HDR10 encoding stage, a H.264 codec (Main Profile) at 8 bits as core. The three HDR sequences proved that the PQ encoding efficiency in 8 bits compared to the 10-bit system reached similar results regarding the objective metrics. However, the encoding is only applicable for PQ-enabled display devices.

The remainder of this paper is organized as follows: an overview of the proposed system is presented in Section II, the objective and subjective results in Section III and the study case in Section IV. Finally, the conclusions are presented in Section V.

II. HDR TELEVISION SYSTEM

Figure 1 shows the general scheme of the proposed system. For reusing the current television head-end infrastructure a 10 bit PQ-TF is applied to the uncompressed video generated at the production and Post-Production stage. Producers can use PQ-enabled displays, such as the HDR SIM2 [10], to reference and adjust technical details of the video, having in mind the representation of the real scene. Then, this PQ signal is redirected to the High Dynamic Range Reducer process, which performs the tone mapping process of the HDR samples and generates the gamma-corrected video samples according to the BT.709 OETF. Likewise, the HDR Reducer process generates the metadata information, which is then encapsulated in a Program Elementary Stream (PES) Packet, signaled by the Packet Identification (PID) according to the MPEG Systems Standard [11]. This PID warrants the video infrastructure be independent of the customizable development of video encoders manufacturers. It is also proposed that the carrying of this information be via an IP network to an MPEG multiplexer.

At the processing stage, the uncompressed YCbCr video samples pass through the 8-bit infrastructure towards the H.264 codec, which compresses the input video in lower bitrates. The output signal can be carried via a IP network or asynchronous physical interfaces directly connected to the MPEG multiplexer, which assigns the number of the metadata PID with the Output Transport Stream (TS) of the matched
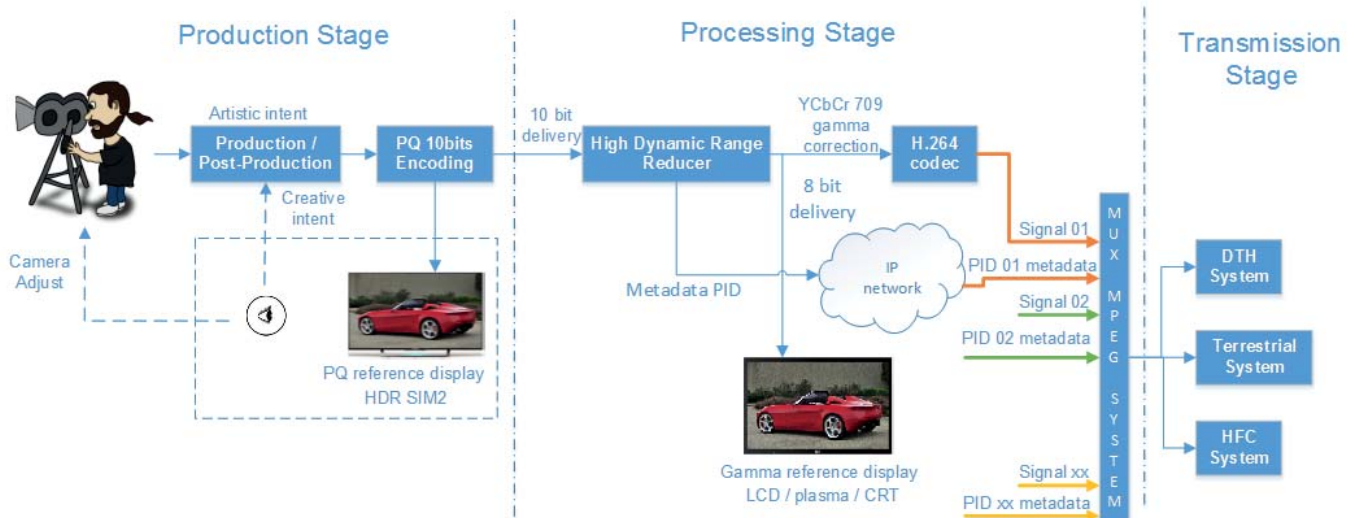
Fig. 1. General Proposed Scheme

service. Finally, the TS could feed different transmission system, either a Direct to Home (DTH), Terrestrial or a Hybrid-Fiber-Coaxial (HFC) service.

In Figure 2 , the reception process is shown, either RF or Fiber. It is considered two type of Set-Top Box (STB), the HDR STB and the Standard Dynamic Range STB. In order to maintain the STB legacy and the compatibility with the existing 8-bit display devices, the current (STB) decodes the video samples and displays the video on Standard Definition (SD) - SDR and High Definition (HD)- SDR television sets. In Figure 2 , the reception process is shown, either RF or Fiber. It is considered two type of Set-Top Box (STB), the HDR STB and the Standard Dynamic Range STB. In order to maintain the STB legacy and the compatibility with the existing 8-bit display devices, the current (STB) decodes the video samples and displays the video on Standard Definition (SD) - SDR and High Definition (HD)- SDR television sets. The HDR STB performs the inverse tone mapping process in order to retrieve the HDR Samples and be displayed on HD - HDR television set.

Some final considerations of the final proposal are: It is known that commercial HDR distribution pipeline is not yet viable because only propotype devices exist [3], it means that current HDR displays are only a glimpse into what future displays can achieve. This work tries to simulate the real problems and address the concerns about future deployments of a HDR TV System. That is why, science and researching are always ahead of the development. Furthermore, this proposal is a scalable solution because when the HDR10 system is being deployed, the Reducer process may be replaced, as well as the H.264 video codec. The 10-bit PQ signal can enter directly to the newest codec, such as the HEVC. Until then, a compatible television infrastructure is of high importance and imperative.

III. OBJECTIVE AND SUBJECTIVE RESULTS

For the laboratory experiments, the Test Sequences [12] used as an anchor in the ITU-R SG06 group are processed.
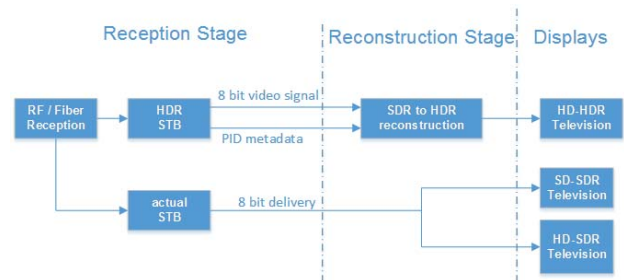

Fig. 2. Reception Scheme

These are: *FireEater*, *Market*, *ShowGirl2*, *Balloon Festival*, *EBU_04_Hurdles*, *EBU_06_Starting*, and *Sunrise*.

A modified version of the software HDRTools v-15 [13] is used to implement the proposed High Dynamic Range Reducer and the SDR to HDR Reconstruction process and the JM 19.0 H.264/AVC reference software [14] for the compression process. Additionally, the HDRMetrics option is used to generate the following objective metrics: $tPSNR\_XYZ$, t_OSNR_XYZ, $PSNR\_MD0100$, $PSNR\_L0100$ and $PSNR\_DE100$.

The final proposal and the HDR10 System [15] are compared, considering the video codec, H.264, in both cases. The simulation of different coding scenarios is reached by modifying the Quantization Parameter (QP): 20, 22, 24 and 28. The assessments that are made to the proposed scheme try to know if it fulfills one of the main features of a HDR Video encoding proposal, which is to preserve the quality of the SDR and HDR contents.

In the HDR domain, as expected, the HDR10 System presents a better compression efficiency than the proposed system for transformed domain-based metrics that involves the tristimulus values of the CIE1930 colorspace, the t_PSNR_XYZ and t_OSNR_XYZ. However, for *Market*, *BalloonFestival*, *ShowGirl* and *EBU_06* sequences, the proposed scheme presents a better compression effi-

ciency than the HDR10 System for color-oriented metrics, the $PSNR\_DE100$ and $PSNR\_MD0100$. Also the metric $PSNR\_L0100$, which evaluates the luminance quality only, has similar behavioral curves between the two systems except for the *FireEater* sequence. Figure 3 and Figure 4 are the results for the *Market* Sequence.

The *FireEater* sequence is a special case because the HDR10 System presents noticeable superior results in all the metrics used in this work. This can be explained by the fact that the histogram of this image has centered in low luminance levels, between 0.00001 and 1 nit. In this range, the PQ signal redistributes the code levels of low luminances of the more efficient way, however, the gamma system exhibits a coarse quantization in the darker regions, since it is well above the visual limits. For this reason, is expected better results for the HDR10 System.
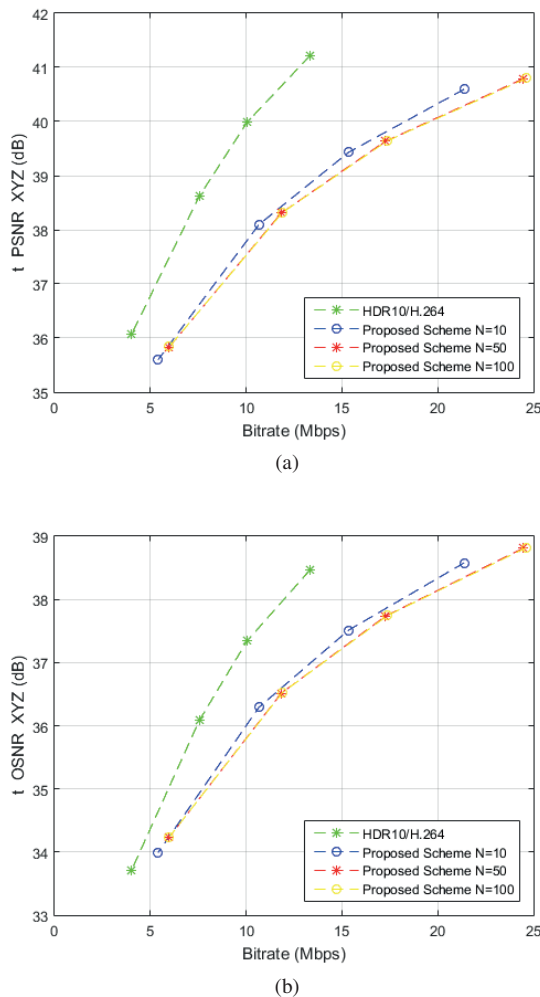

(a)

(b)

Fig. 3. (a) t_PSNR_XYZ; (b) t_OSNR_XYZ

(a)

(b)

(c)

Fig. 4. (a) PSNR_MD0100 (b) PSNR_L0100 (c) PSNR_DE100

In the SDR domain, this work used the $PSNR\_Y'$ metric of the luma component of the $Y'Cb'Cr$ color model. Figure 5a presents the curves of all the tone-mapped sequences with a slope value of 10. Each sequence has different rate-distortion curves. These dissimilarities are caused by the artistic intent of the producer. Also, the high motion scenes generates high bitrates such as depicted in the *EBU_04* sequence. The
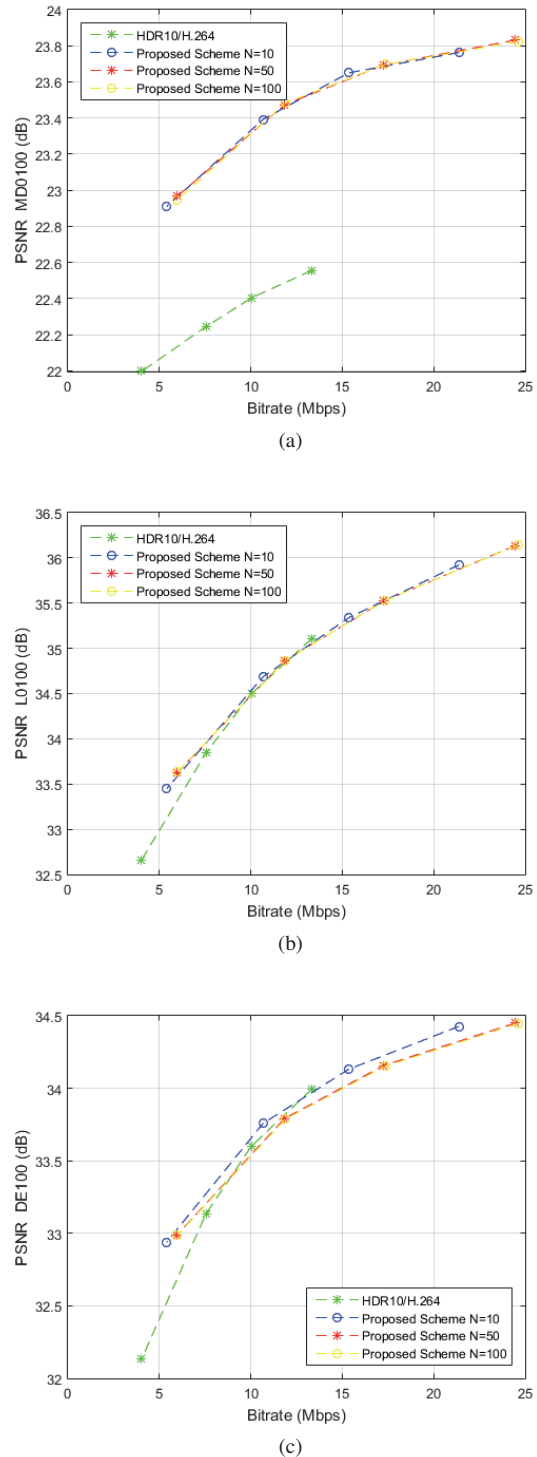
Market sequence also, presents higher bitrates due to the high presence of complex textures. The *BalloonFestival*, *ShowGirl* and *Sunrise* sequences have a moderate bitrate since the three sequences have a moderate contrast and high presence of planar regions. Finally, the *FireEater* and *EBU_06* sequences have the lower bitrates because present low motion scenes and planar regions.

This work used the Absolute Category Rating (ACR)
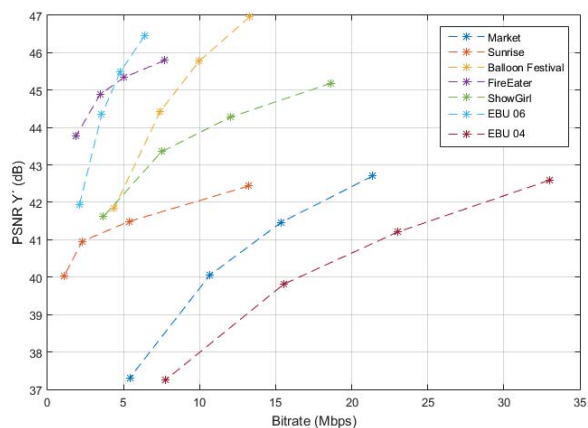
(a)
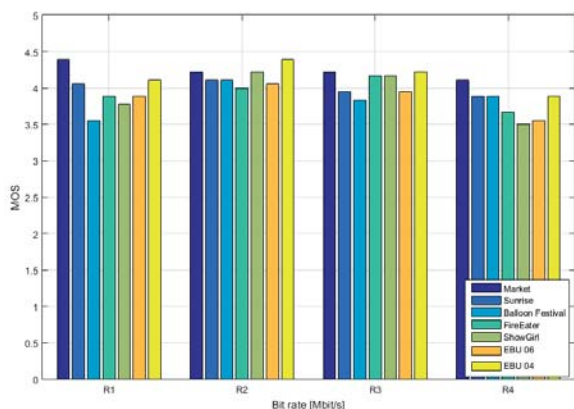
(b)

Fig. 5. (a) Objective metrics of the tone-mapped sequences; (b) Subjective metrics of the tone-mapped sequences

method as specified in the ITU-T Recommendation P.910 [16] for the subjective assessment. In total, were 18 participants with an average age of 31 years. When showing the sequence of images to the participant, the first seven videos were the ones with the highest bitrate, which means a QP of 20. Then, the videos with a QP value of 24, 28 and 22 were projected progressively. The results contrasted that on average all images were evaluated above a value of MOS 3. The sequences with the poorer results were *ShowGirl* and *EBU_06* sequences with a bitrate *R4*. The MOS values against the different bitrates are depicted in Figure 5b. Table I presents the reached bitrates, *R1, R2, R3 and R4*, of the tone-mapped sequences. This information will be of great help in the design of a HDR TV system in the short term.

IV. STUDY CASE

According to the bitrates obtained in Table I, video engineers could estimate the overhead bitrate that would suppose the deployment of a HDR TV system with backward compatibility, considering the legacy television system.

This study case considers the measured bitrates of the main Brazilian broadcast television in the City of Campinas, Sao

Paulo [17]. Table II presents the bitrate of the video PID of each station. The bitrate range is between 8.7 and 15.6 $Mbps$. Usually, when it is designed a television system, the broadcasters resolve to label the type of television programming offered by a channel. These are known as specialty channels and are focused on a single genre, subject or targeted television market. For example, the sports channel broadcasts sporting events, sport news and other related programming. For this content, higher bitrates are assigned. For a cartoon channel, normally, lower bitrates are assigned.

Currently this channel allocation is widely used by companies that develop video encoders. A statistical multiplexing is defined as the compression of a group of services that share information about the variability of their images. It is possible a coding gain of the order of 20 to 30%, in comparison with the coding efficiency when compressing a channel independently.

The bitrate tagged as *R3* reaches good results and mantain a optimal trade-off between bitrate and distortion. The maximum bitrate is 15.537 $Mbps$ and the lowest is 2.285 $Mbps$. The Station B could be designed to broadcast a HDR service of a sport event and other natural images with no distortions, however the station F may be designed to process more natural images with no high motion, such a news channel. Finally, the station C may be designed to process content with much texture and detailed regions such as a documentary channel. Consider that, the kind of programming that presents scenes such as the *FireEater* sequence is unlikely to display on broadcast channels.

From a technical point of view, in order to upgrade the television infraestructure, it is recomendable to change first the video cameras by those one that can record HDR native content. The HDR Reducer process can be added as an option by the future video encoders. They could support two types of video input, a digital video interface with gamma correction and a PQ signal. Whether the HDR version is used, a network interface would be necessary to distribute the metadata information via an IP network towards the MPEG Multiplexer, which assigns it to a certain channel. Finally, this new PID can be standardized according to the chosen digital television standard.

V. CONCLUSION

The main contribution of the work relies on the design of a HDR TV system with backward compatibility. This is a cost-effective solution because are reusing the current allocated bandwidth, enabling the deployment of a new multimedia service in a television system.

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TABLE I
BITRATE OF THE SEQUENCES

Sequence	R1 ($Mbps$)	R2 ($Mbps$)	R3 ($Mbps$)	R4 ($Mbps$)
Market	21.379	15.347	10.661	5.407
FireEater	7.721	5.023	3.463	1.891
Sunrise	13.242	5.366	2.285	1.075
ShowGirl	17.169	11.005	6.965	3.550
EBU_06	6.383	4.779	3.560	2.101
BalloonFestival	13.299	9.956	7.418	4.378
EBU_04	32.983	23.025	15.537	7.779

TABLE II
BITRATE OF DIGITAL TELEVISION CHANNELS [17]

Station	Transmission Modes	Channel ($Mbps$)	Layer B ($Mbps$)	Video HD ($Mbps$)	Null PID ($Mbps$)
A	64QAM - 3/4 - 1/16	18.3	17.8	15.2	2.0
B	64QAM - 3/4 - 1/8	17.3	16.9	15.6	1.0
C	64QAM - 3/4 - 1/16	18.3	17.8	11.8	4.0
D	64QAM - 3/4 - 1/8	17.4	16.9	10.5	5.9
E	64QAM - 3/4 - 1/16	18.4	17.8	14.5	2.9
F	16QAM - 5/6 - 1/16	13.6	13.2	8.7	3.6
G	16QAM - 2/3 - 1/8	10.4	10.0	9.7	0.1
H	64QAM - 3/4 - 1/8	17.3	16.9	14.2	1.7
I	64QAM - 3/4 - 1/8	17.3	16.9	12.3	4.2

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