MINMAX Rate control in near-lossless video encoders for real-time data transmission

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Problem definition

Range of application:

- High throughput wireless video broadcasting systems (ex., WirelessHD[1], IEEE 802.15.3c[2]);

Task definition:

- Development of the rate control algorithm based on JPEG-LS standard;

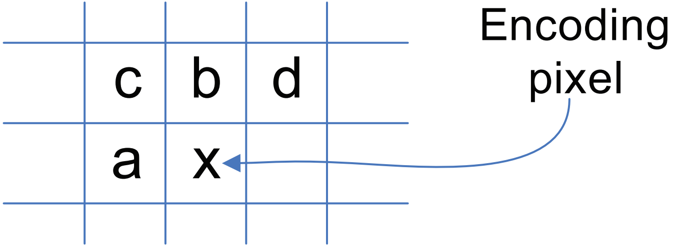
Algorithm's restrictions:

- Computational complexity (single-pass algorithm);
- Low-latency data transmission;

[1] http://www.wirelesshd.org/

[2] http://www.ieee802.org/15/pub/TG3c.html

JPEG-LS standard

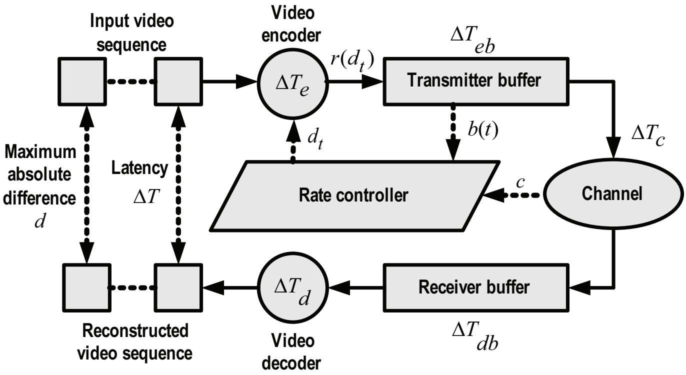


$$\text{encoding mode} = \begin{cases} \texttt{run - series of equal pixels are encoded} \\ \texttt{regular - difference } x - Px \texttt{ is encoded} \end{cases}$$

$$Px = f(a, b, c) \texttt{- predicted value.}$$

Possible to encode with specified maximum absolute difference.

Latency in transmission system

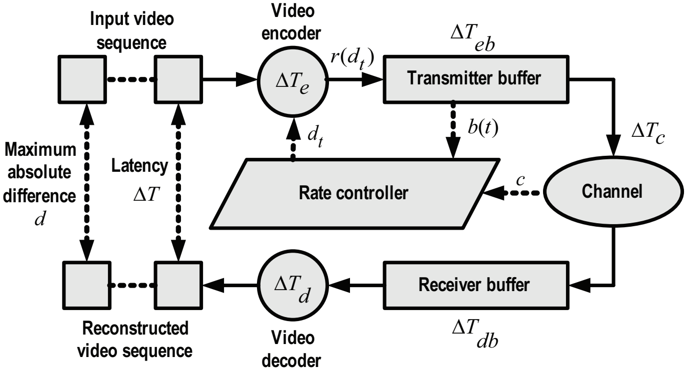


Frame is divided into sequence of slices.

Transmitter's buffer size at time t (c – channel capacity):

$$b(t) = \max\{0, b(t-1) - c\} + r(d_t). \quad (1)$$

Latency in transmission system



$$\texttt{Latency:} \quad \triangle T = \triangle T_e + \triangle T_{be} + \triangle T_c + \triangle T_{bd} + \triangle T_d. \tag{2}$$

$$\triangle T = L, \texttt{if}^1 \begin{cases} B^e_{max} = B^d_{max} = L \cdot c \\ b^e(t) \leq B^e_{max}. \end{cases} \tag{3}$$

[1] A.R. Reibman, B.G Haskell, "Constraints on variable bit-rate video for ATM networks", *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 2, Issue 4,pp. 361 – 372, 1992.

MINMAX optimization task for rate control

MINMAX quality criteria[1]:

$$\textit{minimize} \max_t d_t. \tag{4}$$

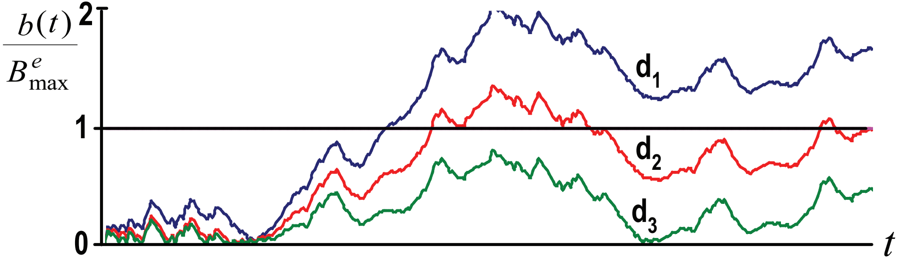
MINMAX optimization task[2]:

$$\begin{cases} \textit{minimize} \max_t d_t \\ b(t) \leq B^e_{max}. \end{cases} \tag{5}$$

[1] N. Cherniavsky, G. Shavit, M. F. Ringenburg, R. E. Ladner, "Multistage: A MINMAX Bit Allocation Algorithm for Video Coders" *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 1, pp. 59 – 67, 2007.

[2] E. Belyaev, A. Turlikov and A. Ukhanova, "Rate-distortion control in wavelet-based video compression systems with memory restriction" *XI International Symposium on Problems of Redundancy in Information and Control Systems – Redundancy'07*, St.-Petersburg, Russia, pp. 13–17., 2007.

Consecutive search



$$
\left.\begin{array}{l}
d_1 < d_2 < d_3 \\
r(d_1) < r(d_2) < r(d_3) \\
\exists t_1 > 0 : b_1(t_1) > B^e_{max} \\
\exists t_2 > 0 : b_2(t_2) > B^e_{max} \\
\exists t_3 > 0 : b_3(t_3) > B^e_{max}
\end{array}\right\}
$$

$\tilde{d} = d_3$ - decision made by consecutive search.

Theorem 1. Decision made by consecutive search algorithm is solution for MINMAX optimization task.

Proof. Let's suppose $\tilde{d} = d_i$.
So for each step $j < i$ for every slice t $x_t = d_j$ and from algorithm's description $\rightarrow$ after encoding slice τ:

$$\tilde{b}(\tau) > B^e_{max}.$$

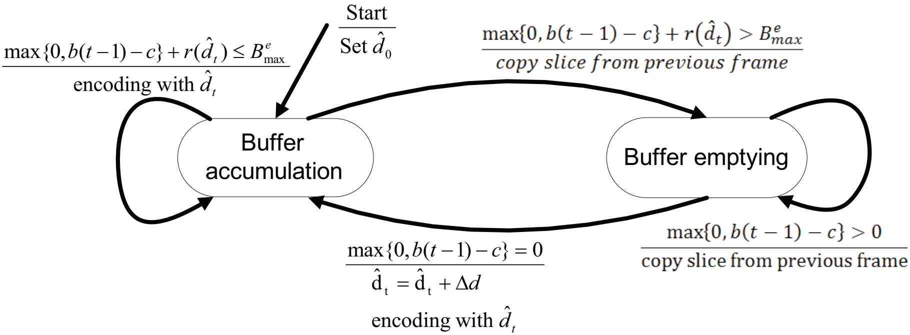
Let's choose any sequence $y_1, y_2, \ldots, y_N$, where $y_t \leq d_j$.

$$y_t \leq x_t \rightarrow r(y_t) \geq r(x_t).$$

$b(t)$ – number of bits in buffer, when slice t is encoded with y_t.
If $\tilde{b}(0) = b(0) = b_0$, then $\tilde{b}(t) \leq b(t)$. So

$$\exists \tau' \leq \tau : b(\tau') > B^e_{max}.$$

Proposed algorithm



Theorem 2. After adaptation to channel's speed ($t \geq \tau$):

$$\hat{d}(t) < \tilde{d} + \Delta d. \qquad (6)$$

Proof. $\tilde{b}(t)$ – amount of bits in buffer during consecutive search.
From algorithm's description:

$$\tilde{b}(t) \leq B^e_{max}.$$

Let's suppose that initial value

$$\hat{d}_0 \leq \tilde{d}.$$

Assume that following may be fulfilled:

$$\exists \tau : \tilde{d} \leq \hat{d}_\tau < \tilde{d} + \Delta d$$

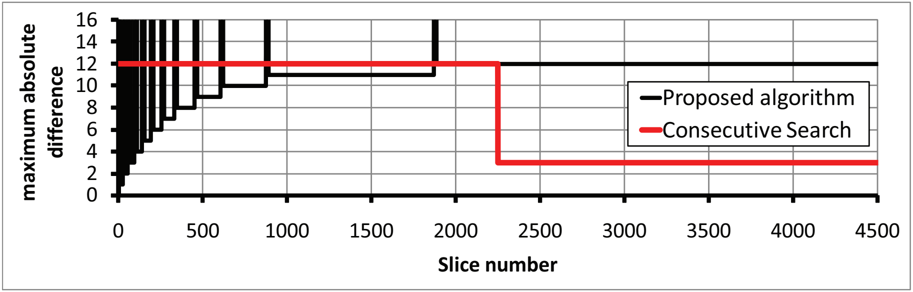
for the first time.
From algorithm's description at the moment $\tau : b(\tau) = 0$

$$r(\hat{d}_t) \leq r(\tilde{d}), t \geq \tau$$

then

$$b(t) \leq \tilde{b}(t) \leq B^e_{max}.$$

Experimental results



Scene changing detection and virtual buffer conception

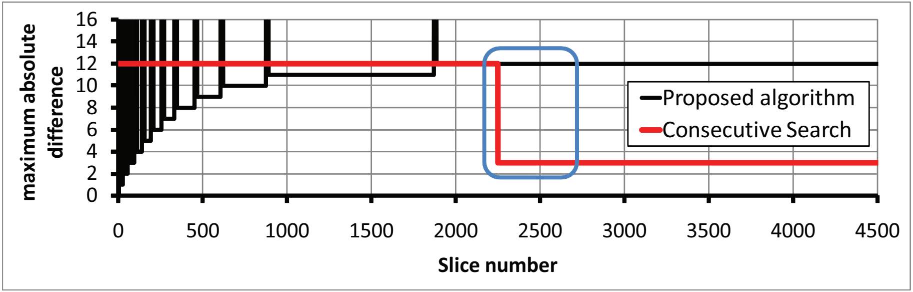
$$b^-_{virt} \leftarrow \begin{cases} b(t), \texttt{if}\, t = t^*, \\ \max\{0, b^-_{virt}(t-1) - c\} + r_{virt}(\hat{d}_t - \Delta d^-_{virt}), \texttt{if}\, t \neq t^*. \end{cases} \quad (7)$$

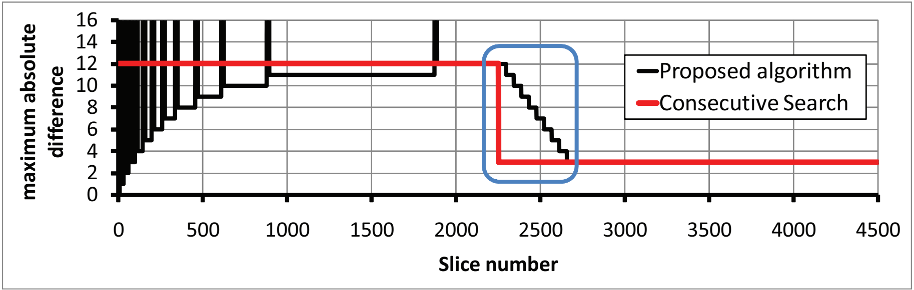
$$\Delta r^-_{virt} \leftarrow \sum_{t=t^*}^{t^*+n-1} r_{virt}(\hat{d}_t - \Delta d^-_{virt}) - n \cdot c, \quad (8)$$

where t^* is a number of the first slice in frame,
n is a number of slices in the frame.

$$\begin{cases} \max\limits_i \{b^-_{virt}(i)\} \leq B^e_{max}, \\ \Delta r^-_{virt} \leq 0. \end{cases} \Rightarrow \hat{d}_t \leftarrow \max\{0, \hat{d}_t - \Delta d^-_{virt}\}. \quad (9)$$

Experimental results with scene changing detection





Algorithm adaptation time decrease

$$b^+_{virt} \leftarrow \begin{cases} 0, \mathtt{if}\, t = t^*, \\ \max\{0, b^+_{virt}(t-1) - c\} + r_{virt}(\hat{d}_t + \Delta d^+_{virt}), \mathtt{if}\, t \neq t^*. \end{cases} \quad (10)$$

$$\Delta r^+_{virt} \leftarrow \sum_{t=t^*}^{t^*+n-1} r_{virt}(\hat{d}_t + \Delta d^+_{virt}) - n \cdot c. \quad (11)$$

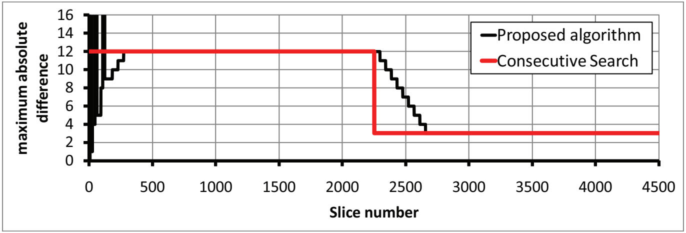
where t^* is a number of the first slice in frame,
n is a number of slices in the frame.

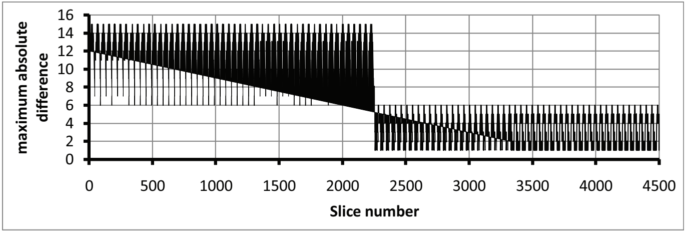
$$\left[\begin{array}{l} \max\limits_i \{b^+_{virt}(i)\} > B^e_{max}, \\ \Delta r^+_{virt} > 0. \end{array} \right. \quad \Rightarrow \hat{d}_t \leftarrow \hat{d}_t + \Delta d^+_{virt}. \quad (12)$$

$$\Delta r \leftarrow \sum_{t=t^*}^{t^*+n-1} r(\hat{d}_t) - n \cdot c. \quad (13)$$

$$\Delta r > 0 \Rightarrow \hat{d}_t \leftarrow \hat{d}_t + \Delta d. \quad (14)$$

Comparison of proposed algorithm and rate control[1,2]





[1] J. Jiang, C. Grecos, "A low cost design of rate controlled JPEG-LS near lossless image compression" *Image and Vision Computing 19*, pp. 153–164, 2001.

[2] T. Tsai, S. Kao, Y. Lee, "The segment-based rate control algorithm in JPEG-LS for bandwidth-efficiency applications", 2008.

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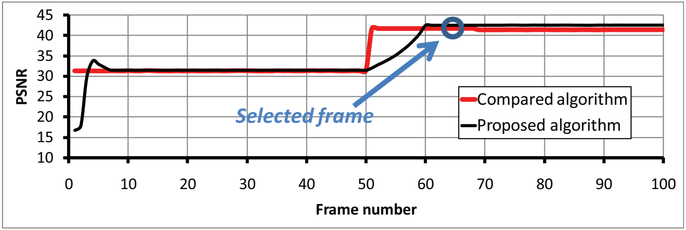

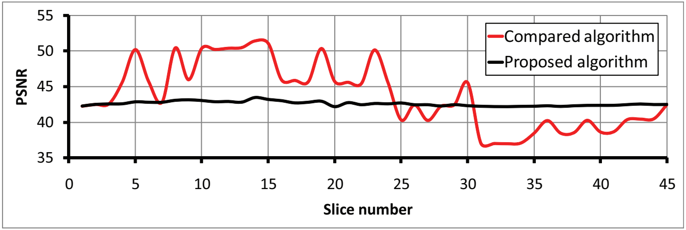

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