Video transmission over high-speed WPAN's based on low-power data compression

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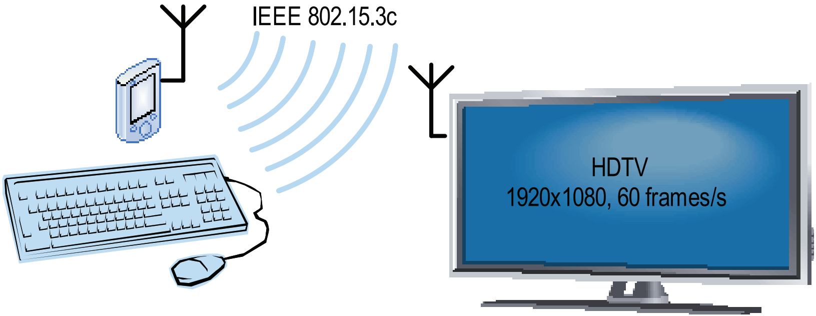
Video transmission over high-speed WPAN's [1] [2] [3]



- System properties:
  - Transmission rate up to 6Gbps;
  - Low-power data transmitter.

[1] http://www.ieee802.org/15/pub/TG3c.html
[2] http://www.wirelesshd.org/
[3] http://wirelessgigabitalliance.org/

System restrictions and requirements

- System restrictions:
  - Low-memory and low-complexity video processing;
  - One-pass processing only is possible;
- System requirements:
  - Very low transmission latency (1-3 ms);
  - Continuous video playback at the receiver;
  - Acceptable visual quality for wide types of video sources:
    - ⋆ sequences of computer graphics, snapshots;
    - ⋆ natural and mixed images.

Possible solutions

- Uncompressed video transmission[1];
- Intra single-layer video coding[2];
- Intra scalable video coding[3];
- Distributive video coding[4].

[1] H. Singh, Jisung Oh, Changyeul Kweon, Xiangping Qin, Huai-Rong Shao and Chiu Ngo, "A 60 GHz wireless network for enabling uncompressed video communication", *IEEE Communications Magazine*, 2008

[2] E. Belyaev, A. Dogadaev and A. Ukhanova. "MINMAX rate control in near-lossless video encoders for real-time data transmission", *XII International Symposium on Problems of Redundancy in Information and Control Systems*, 2009.

[3] M.Gallant and F. Kossentini, "Rate-distortion optimized layered coding with unequal error protection for robust Internet video", *IEEE Transactions on Circuits and Systems for Video Technology*, 2001.

[4] T. Kuganeswaran, X. Fernando, L. Guan, "Distributed video coding and transmission over wireless fading channel", *Canadian Conference on Electrical and Computer Engineering*, 2008.

Possible solutions comparison

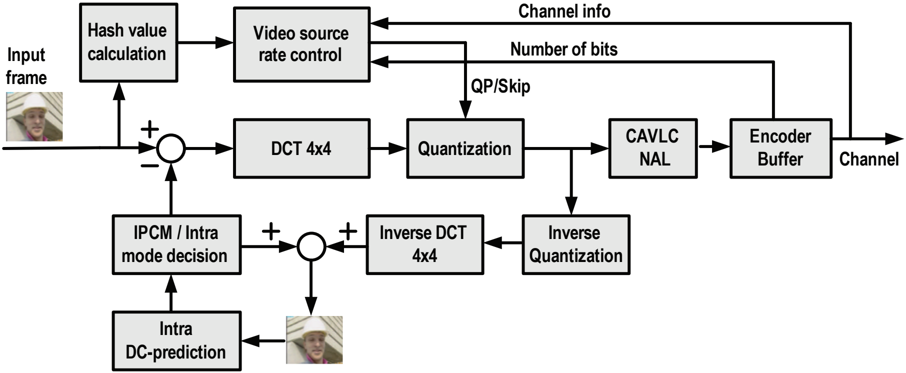
Solution	Encoder complexity	Decoder complexity	Compression efficiency	Link/PHY layers modification
Uncompressed video transmission	very low	very low	very low	yes
Intra single-layer video coding	low	low	medium	no
Intra scalable video coding	medium	medium	low	partly
Distributive video coding	low	high	high	yes

Agenda

Intra single-layer video compression and transmission over high-speed WPAN's

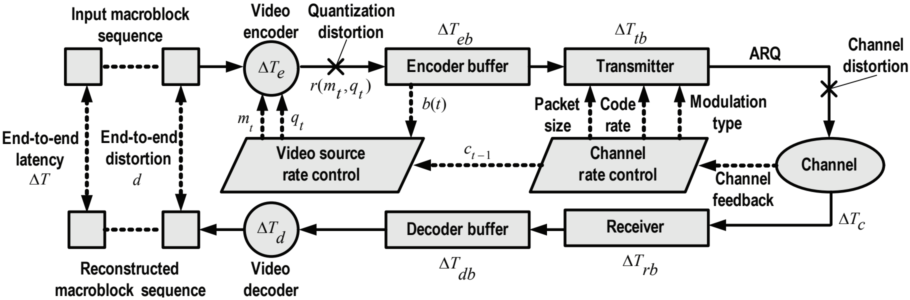
- H.264/AVC low-complexity single-layer video compression;
- Video transmission system description
  - End-to-end distortion in video transmission system;
  - End-to-end latency in video transmission system;
  - MINMAX optimization task description.
- Main idea of the video source rate control;
- Video transmission system model;
- Practical results;
- Future work.

H.264/AVC low-complexity single-layer video compression



- Low-memory INTRA solution (32 pixel lines);
- DC-Prediction only, 4x4 DCT only, CAVLC;
- Hash function calculation for temporal redundancy removal (by using SKIP macroblock type);

Proposed video transmission system scheme



- *Channel rate controller* chooses the transmission scheme that maximizes the channel throughput;
- *Video source rate controller* chooses the quantization step q_t and macroblocks type $m_t \in \{intra, skip\}$ to provide acceptable visual quality and continuous video playback for given channel throughput.

End-to-end distortion in video transmission system

The end-to-end distortion d_t for unit t:

$$d_t = d(q_t) + d_c,$$

$d(q_t)$ is quantization distortion, d_c is distortion caused by channel errors.

MINMAX quality criteria[1]:

$$minimize \max_t d_t.$$

Packet loss probability for ARQ with n retransmissions:

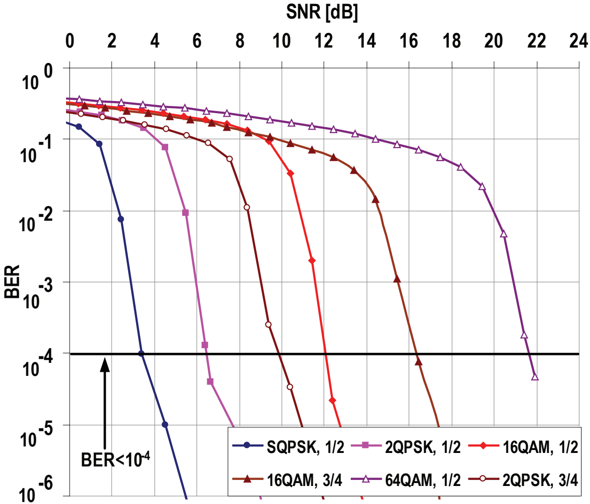
$$p_t^n = (1 - (1 - BER)^l)^n,$$

BER is bit error rate, l is packet length.

If $BER < 10^{-4}$ then l and n can be chosen to guarantee that $p_t^n < 10^{-10}$. Therefore, for further optimization we can **disregard packet losses** and minimize $d(q_t)$ only.

[1] N. Cherniavsky, G. Shavit, M.F. Ringenburg, R.E. Ladner, E.A. Riskin,"Multistage: A MINMAX bit allocation algorithm for video coders", *IEEE Transactions on Circuits and Systems for Video Technology*, 2007.

Bit error rate in IEEE 802.15.3c[1]



[1]IEEE 802.15 WPAN Millimeter Wave Alternative PHY Task Group 3c (TG3c), Contributions and documents, 2009.

End-to-end latency in video transmission system

The number of bits in the encoder buffer after compression unit t:

$$b^e(t) = \max\{0, b^e(t-1) - c_t\} + r_t(q_t, m_t),$$

c_t is number of bits that are transmitted during compression of the unit t,
$r_t(q_t, m_t)$ is bit size of the compressed unit t.
Assume that data on the receiver side is accumulated for some time L after which the decoding and playing starts.

End-to-end latency $\Delta T = L$, if the number of bits in the encoder buffer[1] is

$$b^e(t) \leq b_{eff}(t) = \sum_{i=t+1}^{t+L \cdot f \cdot N} c_i,$$

where $b_{eff}(t)$ is the *effective buffer size*[2], N is a number of units in the frame and f is a frame rate.

[1] A.R. Reibman and B.G Haskell, "Constraints on variable bit-rate video for ATM networks", *IEEE Transactions on Circuits and Systems for Video Technology*, 1992.

[2] A. Ortega and M. Khansari, "Rate control for video coding over variable bit rate channels with applications to wireless transmission", *International Conference on Image Processing*, 1995.

MINMAX optimization task description

For high-speed video transmission we can use high-resolution quantization hypothesis[1] that defines distortion as $d(q) = q^2/12$, therefore MINMAX criteria corresponds to

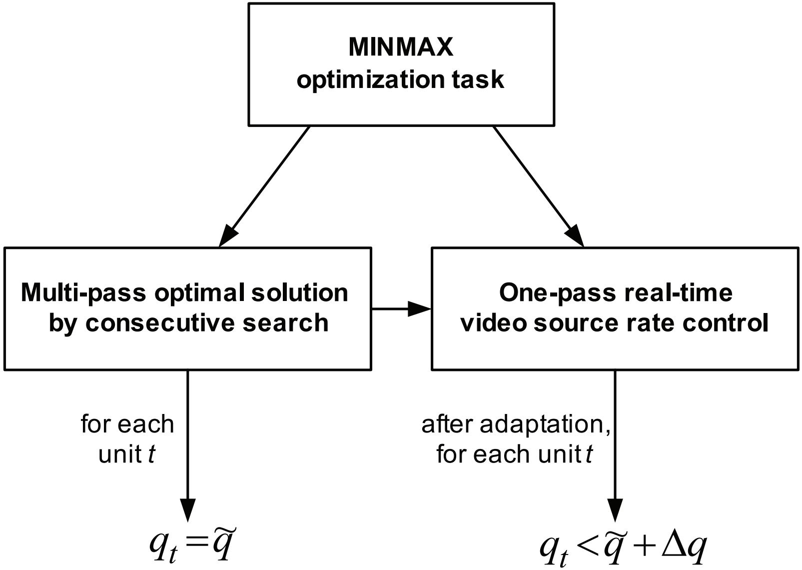
$$\textit{minimize} \max_t q_t. \tag{1}$$

Let us formulate **rate control optimization task** according to the latency requirements and the MINMAX quality criteria. For each unit t it is necessary to choose the quantization step q_t, so that

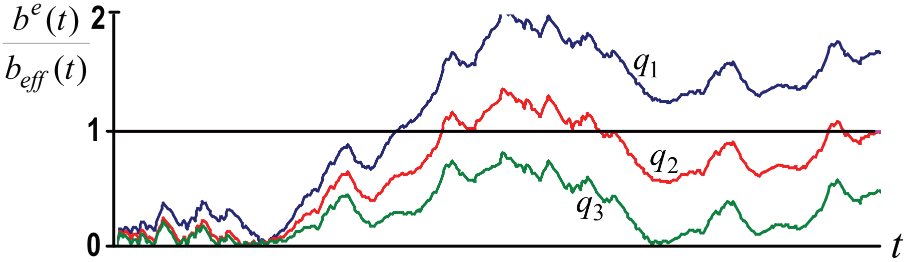
$$\begin{cases} \textit{minimize} \max_t q_t \\ b^e(t) \le b_{\textit{eff}}(t). \end{cases} \tag{2}$$

[1] H. Radha, M. Dai, D. Loguinov, "Rate-distortion modeling of scalable video coders", *International Conference on Image Processing*, 2004.

Video source rate control

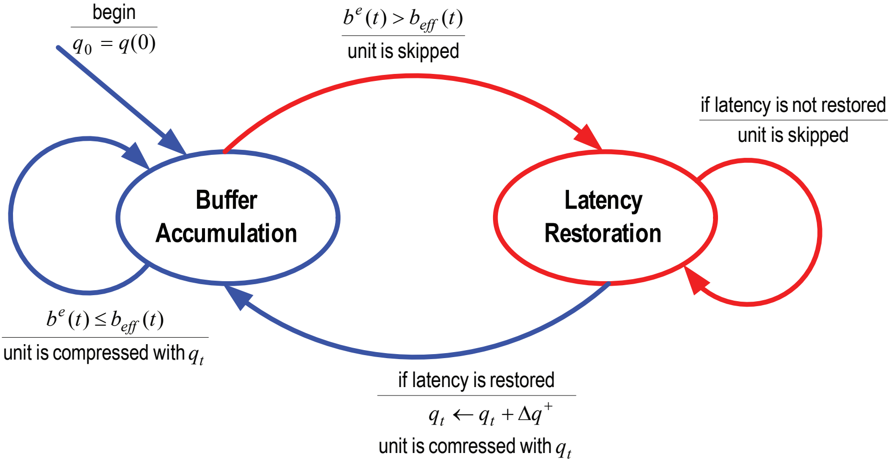


Solution of MINMAX task by consecutive search algorithm



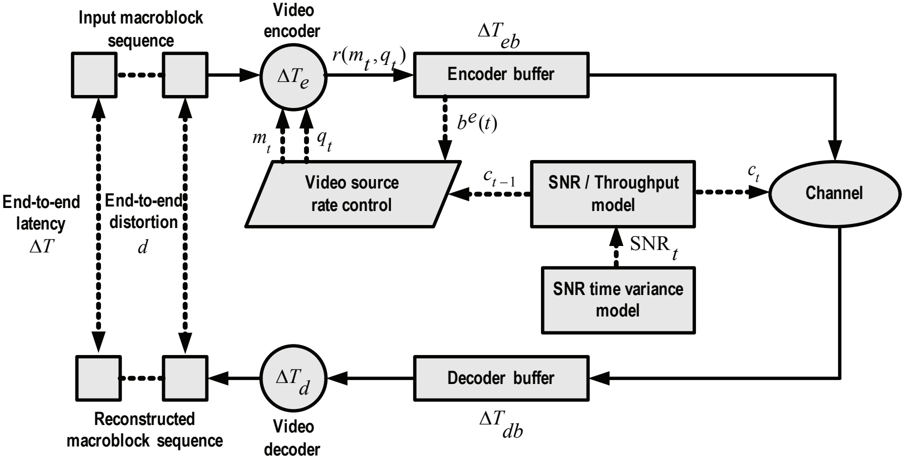
Theorem 1. *Consider $\tilde{q}$ the MINMAX solution found by the consecutive search algorithm. There is no sequence of quantization steps $y_1, y_2, \ldots$ for which $\max_t y_t < \tilde{q}$ that does not lead to the transmitter buffer overflow.*

One-pass MINMAX video source rate control algorithm



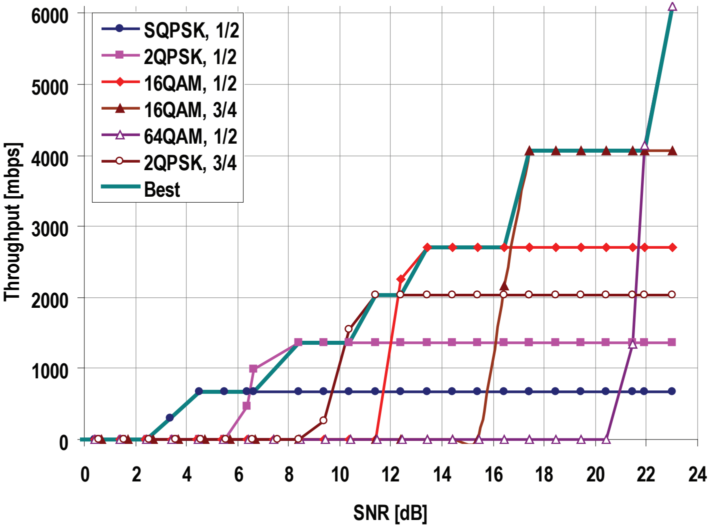
Theorem 2. *Consider that consecutive search algorithm finds the quantization step value $\tilde{q}$. Then for the proposed algorithm with initial value $q_0 \leq \tilde{q}$, the inequality $q_t < \tilde{q} + \Delta q^+$ holds true for any time moment t.*

System model[1]



[1] S. Collonge, G. Zaharia, G. El Zein, "Influence of the human activity on wide-band characteristics of the 60GHz indoor radio channel", *IEEE Transactions on Wireless Communications*, vol.3, pp. 2396–2406, 2004

SNR/Throughput dependence for different MCS[1]

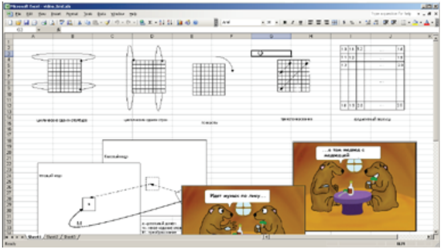


[1] IEEE 802.15 WPAN Millimeter Wave Alternative PHY Task Group 3c (TG3c), Contributions and documents, 2009.

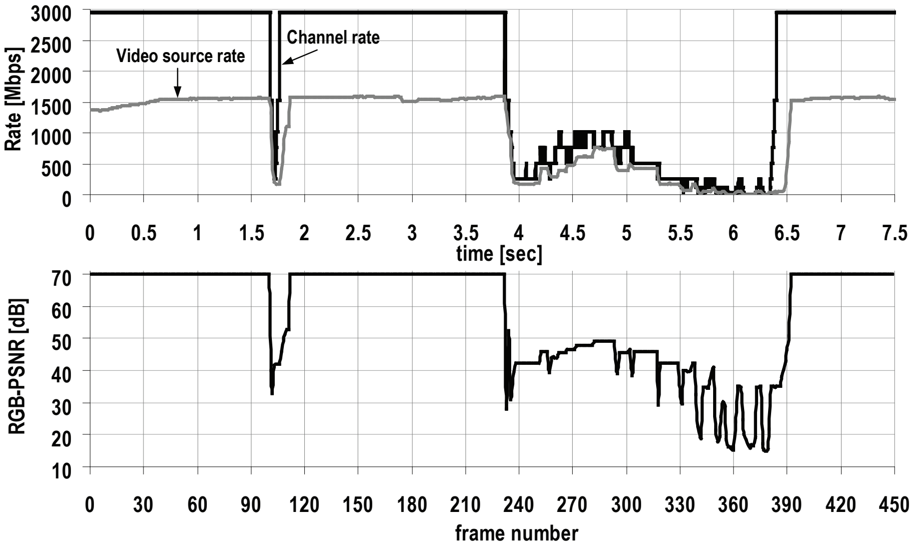
Test video sequences

Breeze

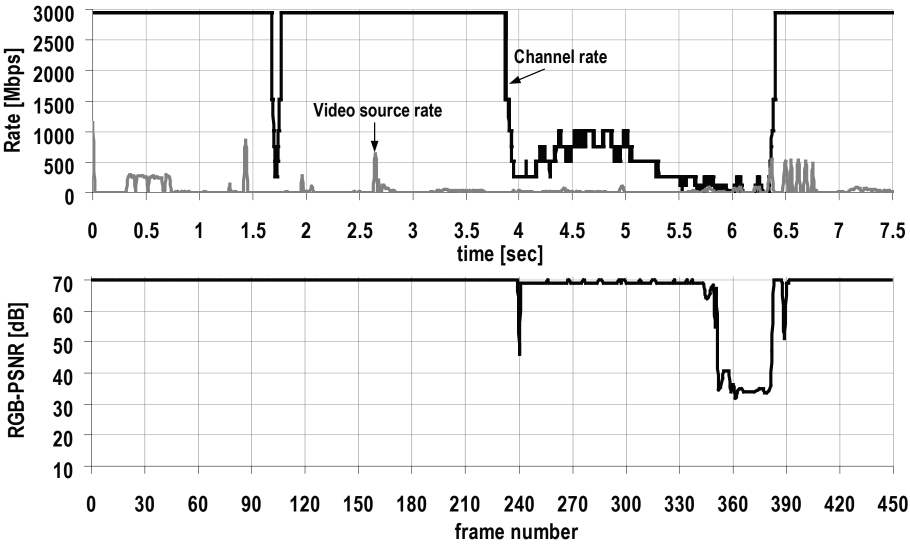
Desktop



Practical results for Breeze



Practical results for Desktop



Future work

- It is interesting to solve the same optimization task for others video processing approaches and compare it with intra single-layer video compression approach.