Low-latency video transmission over high-speed WPANs based on low-power compression

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Video transmission over high-speed WPAN’s

- System properties:
  - Transmission rate up to 6Gbps;
  - Low-power data transmitter.
  - Wide types of video sources:
    - sequences of computer graphics, snapshots;
    - natural and mixed images.

System restrictions and requirements

- **System restrictions:**
  - Low-memory and low-complexity video processing;
  - One-pass compression 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;
  - Lossless video compression supporting.
Possible solutions

- Uncompressed video transmission\(^1\);
- Intra single-layer video compression\(^2\);
- Intra scalable video compression\(^3\);
- Distributive video coding\(^4\).

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\(^1\) 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


### Possible solutions comparison

<table>
<thead>
<tr>
<th>Solution</th>
<th>Encoder complexity</th>
<th>Decoder complexity</th>
<th>Compression efficiency</th>
<th>Link/PHY layers modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncompressed video transmission</td>
<td>very low</td>
<td>very low</td>
<td>very low</td>
<td>yes</td>
</tr>
<tr>
<td>Intra single-layer video compression</td>
<td>low</td>
<td>low</td>
<td>medium</td>
<td>no</td>
</tr>
<tr>
<td>Intra scalable video compression</td>
<td>medium</td>
<td>medium</td>
<td>low</td>
<td>partly</td>
</tr>
<tr>
<td>Distributive video coding</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>yes</td>
</tr>
</tbody>
</table>
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.
- Short description of the video source rate control;
- Video transmission system model;
- Practical results;
- Future work.
INTRA macroblock type, 4x4 DCT only, DC-Prediction only, CAVLC;
Low-memory solution (32 pixel lines);
Hash function calculation for temporal redundancy removal (by using SKIP macroblock type);
IPCM macroblock type to provide compression ratio more than 1;
RGB→YCoCg 4:4:4 reversible color space transform.
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 $m_t \in \{\text{intra, skip}\}$ 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$^1$:

$$\text{minimize} \max_t d_t.$$

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.

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Bit error rate in IEEE 802.15.3c

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 unit $t$ bit size.

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

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

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

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MINMAX optimization task description

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

\[
\text{minimize } \max_t q_t. \tag{1}
\]

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

\[
\begin{cases}
\text{minimize } \max_t q_t \\
 b^e(t) \leq b_{\text{eff}}(t).
\end{cases} \tag{2}
\]

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Video source rate control

MINMAX optimization task

Multi-pass optimal solution by consecutive search

One-pass real-time video source rate control

for each unit $t$

$q_t = \bar{q}$

after adaptation, for each unit $t$

$q_t < \bar{q} + \Delta q$
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.
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

![System model diagram]

\[ \Delta T = d + \Delta T_e + \Delta T_{eb} + \Delta T_d + \Delta T_{db} \]

\[ d_T = \frac{1}{SNR} (t_{tmr} - t_c) \]

References:

SNR/Throughput dependence for different MCS

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

![Graph showing video source and channel rates over time.

The graph displays the rate in Mbps (megabits per second) on the y-axis and time in seconds on the x-axis. Two lines are depicted: one representing the video source rate and the other the channel rate. The video source rate is constant at a lower value compared to the channel rate, which fluctuates significantly, especially around frame numbers 120 and 300. The RGB-PSNR (Root Mean Square Error) in dB is also shown on a separate y-axis, indicating the quality of the transmitted video signal.]
Practical results for Desktop

![Graph showing Rate vs. time and RGB-PSNR vs. frame number for video transmission over WPANs.](image)

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Questions?