Energy-Aware MPEG-4 FGS Streaming

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Outline

- Wireless video streaming
- Scalable video coding
  - MPEG-2
  - MPEG-4 FGS (Fine-Granular Scalability)
- Energy-aware MPEG-4 FGS streaming
- Experimental results
- Conclusions
Wireless video streaming

- Design targets for wireless video streaming
  - High video quality
  - Long service time
- Stable channel for real-time operation
  - Video quality degradation due to channel congestion for error rate
  - Scalable coding technique to be adaptive channel bandwidth variation
- Energy-aware operation to extend the battery lifetime
  - Optimal energy consumption to meet the required video quality

Scalable video coding in MPEG-2

- Scalable video coding
  - A base layer (BL) + an enhancement layer (EL)
- Temporal scalability
  - EL increases frame rate
- Spatial scalability
  - Using down/up sampling
  - EL increases spatial resolution (QCIF → CIF)
- Signal-to-noise ratio (SNR) scalability
  - Using different quantization accuracy
  - EL provides finer image
Deficiency of MPEG-2 scalable coding

- MPEG-2 only provides two layers
- Continuous video quality improvement is desirable to maximally utilize current channel bandwidth

![Diagram showing video quality improvement](image)

MPEG-4 FGS (Fine-Granular Scalability)

- Graceful degradation of video quality under bandwidth variation using hierarchical layer structure
  - A base layer (BL) + an enhancement layer (EL)
- BL guarantees the minimum acceptable video quality
- EL improves the video quality if sufficient channel bandwidth exists
- EL bit-stream can be truncated into any number of bits by using bit-plane coding
  - Provides continuous scalability as channel bit-rate varies
MPEG-4 FGS encoder structure

- Enhancement layer
  = original image – reconstructed image from base layer

DCT coeff. → Q₁/VLC → Base Layer

- VLD/Q₁⁻¹

Q₂/bit-plane coding → Enhancement Layer

DCT: Discrete Cosine Transform
VLC: Variable Length Coding
VLD: Variable Length Decoding
Q₁, Q₂: Quantization Factor for BL & EL

Bit-plane coding

- An enhancement layer consists of several bit-planes obtained by bit-plane coding
- As more bit-planes are decoded, the video quality increases

Channel Bandwidth

ex) if BW₁ < BW_{act} < BW₂
then, base+bp0~1 are sent

\{ EL (=bp0+bp1+bp2+bp3+bp4) \}
\{ BL \}
Energy consumption in video streaming

- Two sources of energy consumption in wireless video streaming
  - Communication energy
    - Transmitting packets (server)
    - Receiving packets (client)
  - Computation energy
    - Packetization (server)
    - Decoding bit-streams (client)

- We target a video streaming system with a server and a mobile client

Energy consumption at the client

\[
E_{\text{CLIENT}} = E_{\text{COMM_CLIENT}} + E_{\text{COMP_CLIENT}}
\]

\[
E_{\text{COMM_CLIENT}} = K_p \cdot (S \cdot \alpha_{RX} + \beta_{RX})
\]

\[
E_{\text{COMP_CLIENT}} = C_{\text{eff}} \cdot V^2 \cdot f_{\text{CPU}} \cdot T
\]

- \( K_p \): number of packets
- \( S \): packet size
- \( \alpha_{RX}, \beta_{RX} \): regression coefficients
- \( C_{\text{eff}} \): effective capacitance
- \( V \): operating voltage
- \( f_{\text{CPU}} \): operating frequency
- \( T \): streaming time
Energy waste at the client

- Video streaming is a real-time operation
  - If the client cannot process all the packets from the server in a given deadline, then the communication energy is wasted with no improvement of video quality

  ex) Arrived packet count : \( A \)
      Decoded packet count : \( M \)

  \[ \text{Video quality} = \min(M, A) \]
  
  If \( A > M \), then \( (A-M) \) packets are useless resulting in energy waste in handling those packets

- For an energy-efficient streaming in which no energy is wasted, \( A \) should be equal to \( M \)

Decoding aptitude

- Decoding aptitude \((M)\) of a mobile client is defined as the amount of data that can be decoded in a given deadline
- \( M \) can be changed by several factors such as the workload and the CPU freq
- Normalized decoding load, \( N \)
  - defined as the ratio \( A/M \)
  - represents the degree of energy waste
  - no energy waste when \( N \) is equal to 1
- To achieve \( N=1 \), the server should know the value of \( M \)
- Client-feedback video streaming
Client-feedback video streaming

- A status packet is periodically sent to the server at regular time intervals
- The server sets the amount of data to be transferred based on the client status: trying to ensure that $N_i = 1$

\[ M_i (\text{decoding aptitude in frame } i) \]

Wireless channel

server

\[ D: \text{deadline for a frame} \]

client

\[ M_0 \quad M_1 \quad M_2 \quad M_{i-1} \quad M_i \]

Simulation results

- Variations in $N_i$ with different $M_i/B$ ratios
  - $B$ : maximum number of packets the server can send
  - $M_i$ trace : 0.8B, 0.4B, 1.2B, 0.5B, 0.7B, 1.4B
- Wireless channel model
  - Gilbert-Elliot model with bit error rate (BER) of $1e^{-5}$ and $1e^{-4}$ for good and bad state, respectively

\[
\begin{array}{|c|c|c|}
\hline
\text{Energy waste} & \text{No FB} & \text{FB} \\
\hline
0.8B & 18.74\% & 0.21\% \\
0.4B & 57.35\% & 2.57\% \\
1.2B & 0\% & 0\% \\
0.5B & 48.49\% & 6.27\% \\
0.7B & 28.69\% & 0\% \\
1.4B & 0\% & 0\% \\
\hline
\end{array}
\]

![Graph showing variations in $N_i$ with different $M_i/B$ ratios](image)
Experimental results (I)

- Generated MPEG-4 FGS bit-streams using a QCIF test video
  A base + FGS with five bit-planes(bp0~4)
  256-byte packet size

- Six test cases
  (I) base layer only
  (II) base + bp0
  (III) base + bp0 + bp1
  (IV) base + bp0 + bp1 + bp2
  (V) base + bp0 + bp1 + bp2 + bp3
  (VI) base + bp0 + bp1 + bp2 + bp3 + bp4

- Peak signal to noise ratio (PSNR) increases as more bit-planes are decoded

<table>
<thead>
<tr>
<th></th>
<th>Size (byte)</th>
<th>Packet number</th>
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<td>1</td>
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<tr>
<td>FGS Header</td>
<td>9</td>
<td>1</td>
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<td>bp0</td>
<td>18</td>
<td>1</td>
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<td>bp2</td>
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<tr>
<td>bp4</td>
<td>3358</td>
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</tr>
</tbody>
</table>

Experimental results (II)

- Apollo testbed II

Main board

PCMCIA board

Memory controller
XScale
SDRAM
PCI connector
PCMCIA slot for WLAN card
Experimental results (III)

- Power consumption in wireless LAN card when receiving packets
- More energy is required to receive larger number of data packets

Experimental results (IV)

- Energy consumptions of the CPU and the WLAN
  - Frame rate 10, 733MHz
- For case (I), the lowest video quality, we achieve about 20% reduction in the WLAN energy consumption by using the proposed client feedback scheme
Conclusions

- A client-feedback power control method is proposed that reduces the redundant energy consumption in a wireless video streaming system.

- By using the proposed method, about 20% reduction in the communication energy is achieved, which is up to 40% of the CPU energy.

- In the future, we will consider the energy reduction of the total streaming system including both the client and the server.