Error-Aware Video Encoding to Extend Energy-QoS Tradeoffs for Mobile Embedded Systems

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1 Problem domain –
2 Specific motivation and problem –
3 Proposal –
4 Contributions –

Categories and Subject Descriptors: []: —;
General Terms:
Additional Key Words and Phrases:

1. INTRODUCTION

(1) Emerging video applications on mobile devices and problem domain
—video applications are becoming more popular.
—energy efficiency is a key property to consider for designing mobile embedded systems.

This is an expanded version of a paper published in the Proceedings of the IFIP Working Conference on Distributed and Parallel Embedded Systems (DIPES) 2008. The current manuscript extends the previous paper by exploring the design space for the partially protected instruction caches and proposing the heuristic algorithms to efficiently find the best configuration with minimal vulnerability under the performance penalty.

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(2) Previous Work
—Energy-aware video applications for mobile embedded systems
—Still, energy-efficient approaches are required to prolong the life of mobile devices.

(3) Problem Definition
—wireless network is not stable.
—error-resilient video encoding is important.
—some error-resilient video encoding is energy-efficient as well.
—what if network is stable (i.e., no errors) but error-resilient video encoding will work as a normal or standard video encoder.

(4) Our approach – Error-Aware Video Encoding (EA-VE)
—Intentional error injection (e.g., frame dropping) can be an effective knob to tradeoff QoS for the energy efficiency.
—QoS-feedbacked mechanism can maintain the video quality in EA-VE schemes.

(5) Results and contributions
—Save the huge amount of energy consumption at the minimal cost of the video quality.
—Our approaches can extend the design space significantly to tradeoff the video quality for the energy reduction or vice versa.

2. THE BACKGROUND
2.1 Energy/QoS-aware Video Encoding
—Overview of quality aware video encoding
—Overview of energy aware video encoding
2.2 Error-Resilient Video Encoding
—Overview of robust video encoding techniques
—Promising Intra Refresh encoding techniques

2.3 Error-Aware Video Encoding: Our Proposal
—passive error-aware video encoding
—error-aware energy reduction at network
—active error exploitation – our proposal

3. OUR APPROACH
3.1 System Model
(1) Our system model
—Mobile Video Conferencing
Fig. 2. System Model (Mobile Video Conferencing) and Frame Drop Types I/II/III for Active Error Exploitation

—CPU and WNI are dominant contributors to power consumption
—Why one path from an encoder to a decoder

3.2 Fundamentals of Active Error Exploitation

(1) Intentional error injection
—Network is unreliable
—ER and EC are designed against network errors
—Error injection such as frame skipping can occur everywhere
—Error injection can affect the following components in terms of EC and QoS
—We study an active error exploitation at the Encoder since it is the most effective

(2) Motivated examples
—Error-aware video encoding techniques can present larger tradeoff spaces compared to a normal video encoder (GOP-15) and an original PBPAIR
—GOP-15 is a base video encoder for comparison, which indicates 15 P-frames between two I-Frames.
—PBPAIR is a previously proposed error-resilient video encoding technique
—EA-PBPAIR presents a novel knob, error-injection rate (EIR), which is able to tradeoff the video quality and the energy consumption

Table I. Energy Consumption Category

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enc EC</td>
<td>Energy consumed by CPU to encode a video stream</td>
</tr>
<tr>
<td>Tx EC</td>
<td>Energy consumed by WNI to transmit an encoded video stream</td>
</tr>
<tr>
<td>Sce EC</td>
<td>Enc EC + Tx EC</td>
</tr>
<tr>
<td>Dec EC</td>
<td>Energy consumed by CPU to decode a received video stream</td>
</tr>
<tr>
<td>Rx EC</td>
<td>Energy consumed by WNI to receive a video stream</td>
</tr>
<tr>
<td>Dst EC</td>
<td>Dec EC + Rx EC</td>
</tr>
</tbody>
</table>

EC = Energy Consumption
3.3 EA-VE: Error-Aware Video Encoding

Fig. 3. Energy Consumption Saving and Quality Degradation of Error-Aware Video Encoder (EA-PBPAIR) compared to a standard video encoder (GOP-15)

3.3 EA-VE: Error-Aware Video Encoding

Fig. 4. Error-Aware Video Encoder consists of Error-Injection Unit and Error-Canceling Unit.

(1) Introduction and wrap-up
   —Intentional error-injection can help VCS save the energy consumption

(2) Two-steps error-aware video encoder
   —Error-aware video encoding technique we present is composed of two units such as error-injection unit and error-canceling unit
   —We present two simple approaches, which exploit the error-tolerance of video data to increase the energy reduction for mobile video applications
   —(i) Error Controller
       —Error-injection unit preprocesses the parameters for the following video encoder, and inserts errors purposely to tradeoff between energy and quality of service
   —(ii) Error-Resilient Video Encoder
       —Error-canceling unit can be a normal video encoder or an error-resilient video encoder.
—They reduce the effects of error-injection thanks to the nature of error-tolerance of video data and/or thanks to the error-resilience.

(3) In conclusion, EA-PBPAAIR can save the energy consumption
—(i)
—(ii)
—(iii)
—(iv)

3.3.1 Frame Dropping

(1) Simple error injection scheme is to skip the frames periodically
—Intelligent frame skipping can increase the quality
—Different strategy from general frame skipping technique
—Any frames can be dropped in EA-VE
—For our approaches, we use “Frame Dropping Technique” at the error-injection unit, and “Error Resilience Video Encoder” at the error-canceling unit

(2) PFD
(3) MDFD

3.3.2 Error Canceling

(1) PBPAIR is energy efficient
—PBPAIR is a video encoding technique which is not only error-resilient but also energy-efficient.
—PBPAIR has two parameters such as IntraTh and PLR (Packet Loss Rate)

(2) GOP
(3) PGOP
3.4 Adaptive EA-VE

Fig. 5. Flowchart of Error Controller for Adaptive EA-VE

(1) We introduce the EIR as a new knob to tradeoff energy and QoS
—It opens and expands the operating points, which are newly discovered.

(2) First approach
—This approach is to inject errors by dropping frames given an EIR
—The sum of an actual network PLR and EIR is an input as Para1 for PBPAIR
—For instance, the actual PLR is 10%, and EIR is 5%, then the parameter PLR to PBPAIR is 15%

(3) Second approach
—To adapt EA-PBPAIR for meeting QoS requirement,
—EIR can be adjusted for dynamic network status
—Change EIR based on the quality feedback from the decoding

(4) Third approach
—AER (Adjusted Error Rate) can be updated to increase the energy saving or to increase the video quality.

4. EXPERIMENTAL SETUP

Fig. 6. Experimental Framework - System Prototype + NS2 Simulator

(1) Experimental Framework
—Integration of System Prototype and NS2 using Perl
(2) System Prototype
(3) Power Values and Parameters for CPU and WNI
(4) Applications
(5) Test sequences such as Akiyo, Foreman, and Coastguard
(6) NS2 Simulator

<table>
<thead>
<tr>
<th>Power Parameters</th>
<th>CPU</th>
<th>WNI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Mode</td>
<td>Active</td>
<td>Idle</td>
</tr>
<tr>
<td>Power (W)</td>
<td>0.411</td>
<td>0.121</td>
</tr>
<tr>
<td>Transition (msec)</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>
5. EXPERIMENTAL RESULTS

5.1 Energy Reduction from Active Error Exploitation

—A set of experiments to show the effects of our error-exploiting on energy reduction without significant quality loss

(1) (A1) The first set of experiments: EA-PBPAIR vs. GOP300 with respect to energy consumption and quality of service at actual PLR = 0, 5, and 10%, respectively
   —keep the transmitted data size the same
   —or include the energy consumption for larger data transmission in EA-PBPAIR

(2) (A2) EA-PGOP vs. PGOP w.r.t. energy consumption and quality of service
   —emphasize the effects of error-injection on energy consumption at PLR = 10%
   —clearly show that EA works for an error-resilient video encoding such as PGOP
Fig. 9. Energy Reduction and Quality Degradation of EA-PGOP compared to PGOP (PLR = 10%, EIR = 10%, AER = 0% and -10%, FOREMAN 300 frames)

—Note that it shows the energy reduction at encoding and decoding while showing the energy overhead for transmission and receiving the video data since PGOP does not have a mechanism to adjust the video quality and the encoding file size as PBPAIR has (e.g., Intra Threshold). However, it is the reason why we present AER, which may increase the amount of errors we injected intentionally to save the energy consumption, especially for the communication energy until the quality is satisfied with our feedback-based mechanism.

—present the quality loss, which is why we propose the feedback-based error control approach in the next section

(3) (A3) EA-GOP vs. GOP w.r.t. energy consumption and QoS
—we apply our active error exploitation for a standard video encoding such as GOP, where we can see the positive impact of error-exploitation on the energy saving at the slight loss of the video quality.

—Again, since there is no detailed mechanism to adjust the size of compressed video data at the encoding process without modifying the default quality-aware mechanisms such as the quantization scale value, we maintain the AER to keep the transmission energy minimal to save the overall energy at the source and at the destination at the least cost of the video quality.

5.2 Sensitivity of Error-Injection Rate and Adjusted Error Rate

(1) The effectiveness of EIR on the energy consumption and the video quality (Fig. 12)

(2) The effectiveness of AER on the energy consumption and the video quality (Fig. 12)

5.3 Energy/QoS tradeoff

(1) Extended tradeoff space for mobile video embedded systems
Fig. 10. Energy Reduction and Quality Degradation of EA-GOP compared to GOP (PLR = 0%, EIR = 10%, AER = 0% and -10%, FOREMAN 300 frames)

Fig. 11. Effects of Error Injection Rate on Energy Consumption and Video Quality (PLR = 10%, FOREMAN 300 frames, Each encoding is constrained with bandwidth)

(2) Effectively reduce the energy consumption of an encoding mobile device at the cost of the video quality
5.4 Feedback-based Error-Injection Control

(1) A set of experiments to show how our proposed feedback-based error-injection control works in order to keep the quality satisfied while minimizing the energy consumption

(2) (B1) changing EIR can show how EIR works for adjusting quality of service for a fixed PLR
   —show how effectively our EA-PBPAIR can be used for adjusting quality by adjusting EIR
   —base is a nominal EA-PBPAIR, i.e., a fixed EIR for error-injection

5.5 Adaptive EA-PBPAIR under Dynamic Network Status

(1) (B2) Also, adjusting EIR for varying PLR dynamically works well
   —Adapt EIR for EA-PBPAIR and Para1 for PBPAIR to satisfy the given quality
   —base is a nominal EA-PBPAIR, i.e., a fixed EIR for error-injection

6. SUMMARY

REFERENCES
Fig. 13. Video Quality vs. Energy Consumption (Each encoding is constrained with bandwidth, EIR = 1% to 50%, PLR = 5%, AER is set to Para1 = 15%, Para2 is varying, FOREMAN 300 frames)
Fig. 14. Energy Saving at the Cost of Video Quality by EA-PBPAIR

(a) AKIYO
(b) FOREMAN
(c) COASTGUARD

Fig. 15. Adaptive EA-PBPAIR with a decrease of EIR vs. EA-PBPAIR with a fixed EIR

(a) Delivered Video Quality
(b) Error Injection Rate

Fig. 16. Adaptive EA-PBPAIR Robust to Varying PLR under Dynamic Network Status