Annotation Integration and Trade-off Analysis for Multimedia Applications

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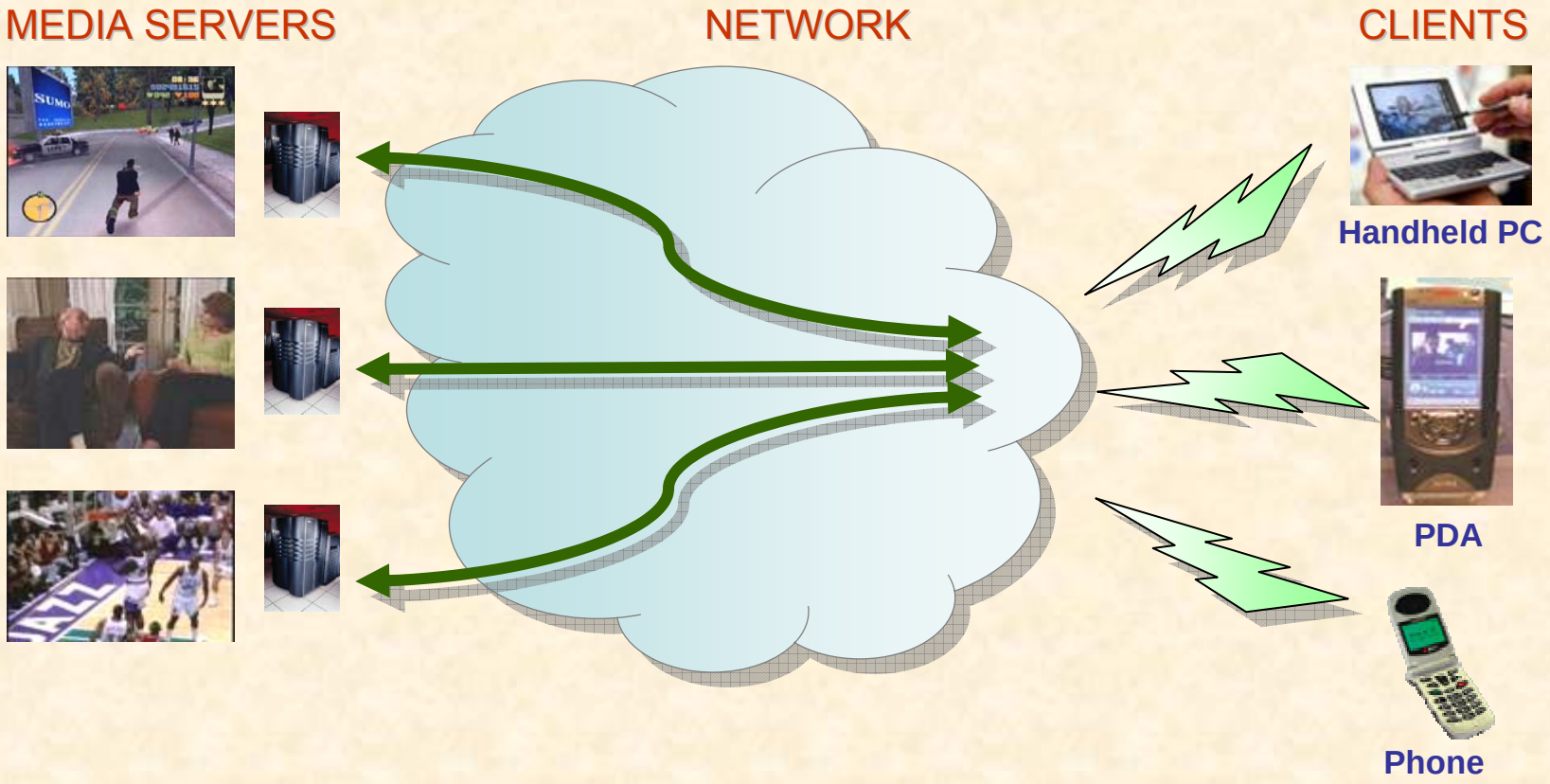
Introduction and Motivation

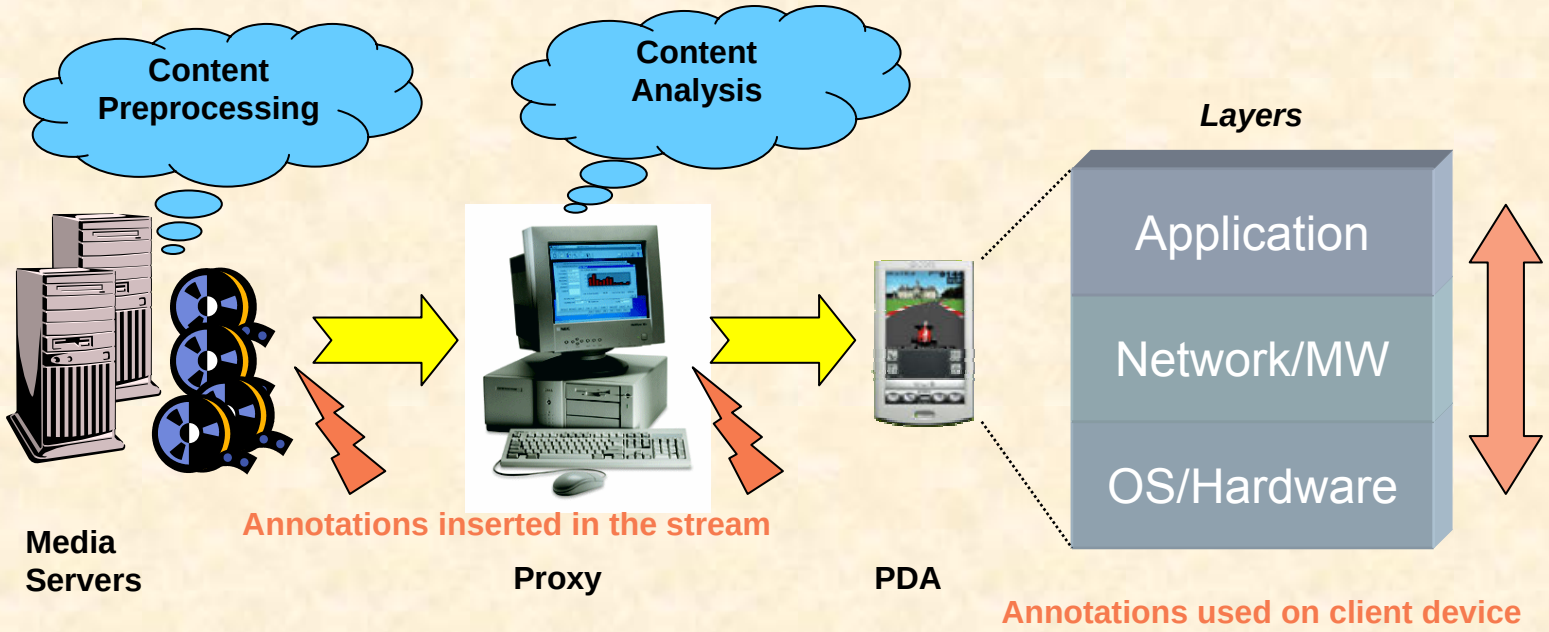


- Mobile devices: popular, complex, media-centric
- New class of applications: multimedia streaming
- Battery technology still lagging behind

Patterns in Multimedia Applications

- Multimedia:
  - Applications follow clear, regular execution patterns [Sherwood et al - 2002, 2003]
  - Data stream – factor for the variation in execution
    - New way to optimize power consumption based on content
    - Analysis allows early, *accurate*, insight into data patterns
    - Annotations can carry this information
      - Data-aware runtime optimizations
- *We proposed a new framework for multimedia streaming based on annotations*

New Framework for Streaming



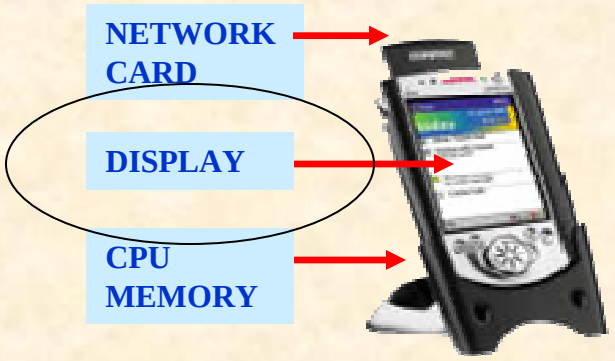
A content-aware framework benefits all abstraction layers, and allows better energy savings through informed power-quality trade-offs and cross-layer interactions.

Data Annotation

- Supplement data stream with info on patterns
- Steps:
  - Profile data stream (offline or online – proxy)
  - Embed profiling info into data stream
  - Use at runtime for optimizations purposes
- Without annotations: data analyzed at runtime
  - Limited knowledge (and no “foresight”)
  - Overhead
- Advantages
  - Info available before the stream is decoded
  - Larger window for analysis

Display Power Optimization

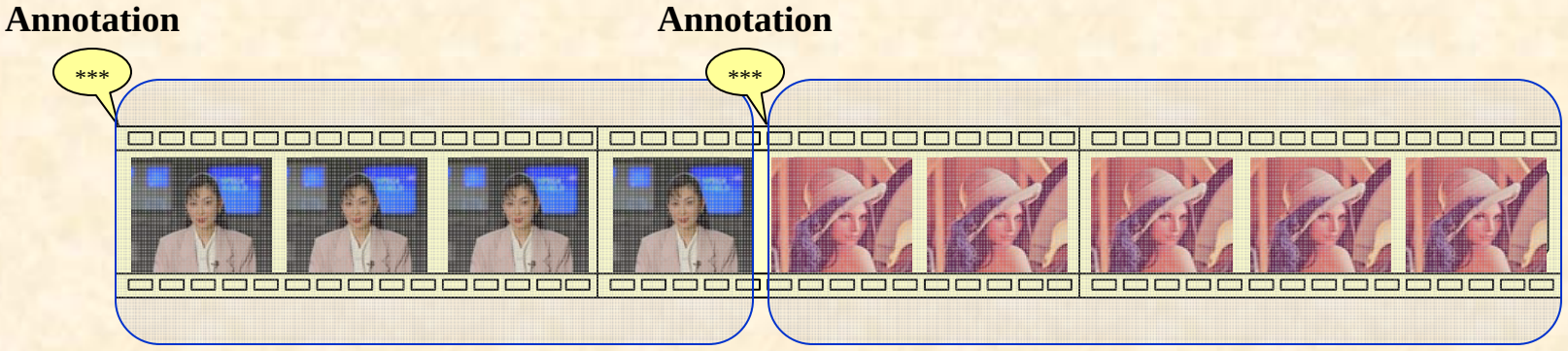
- LCD consumes around 30% of overall power
- Challenges for power management
- Reducing LCD power
  - (Variable-duty-ratio refresh
  - Dynamic color-depth control)
  - Backlight luminance dimming
    - With brightness & contrast compensation
- *We use annotations to characterize brightness variation in a video stream*



[DATE 2006]

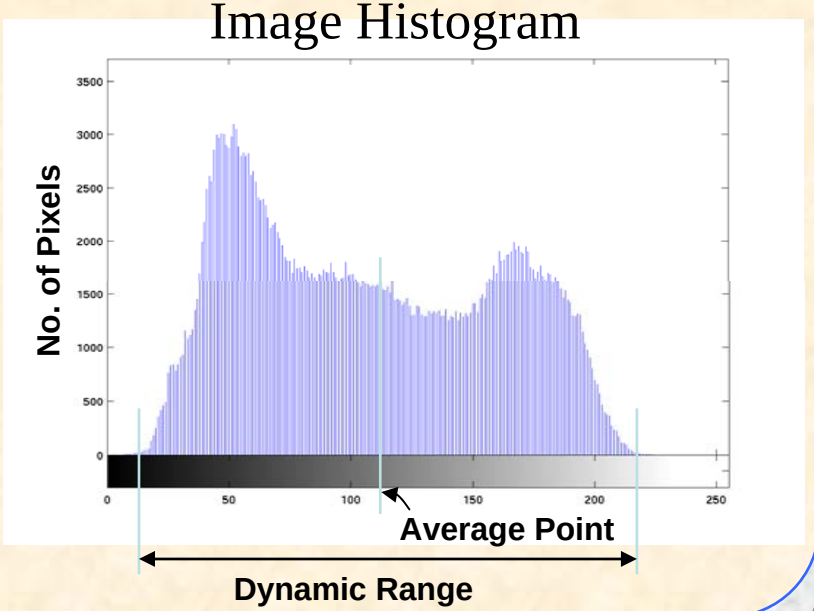
Stream Annotation

- Average brightness varies during the clip
  - Little variation for frames in a scene
  - Annotations can describe the scenes!
- Profile video stream and annotate it
  - Exploit annotations at runtime – backlight adjustment
- Advantages
  - Less overhead for the mobile device
  - More comprehensive analysis (larger window)

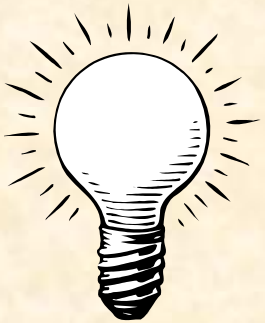


Video Processing

- To reduce power, backlight is dimmed
- Video requires compensation to match it
  - Each frame goes through a compensation step
  - Same compensation for frames in a scene
  - Off-line (server)
- Evaluate the effect with histogram
- Histogram shows
  - Shifts in values
  - Range compression



Frame Compensation

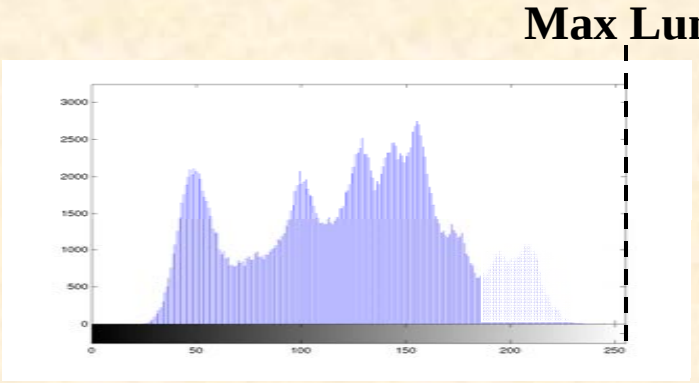


Backlight

LCD Panel

PDA

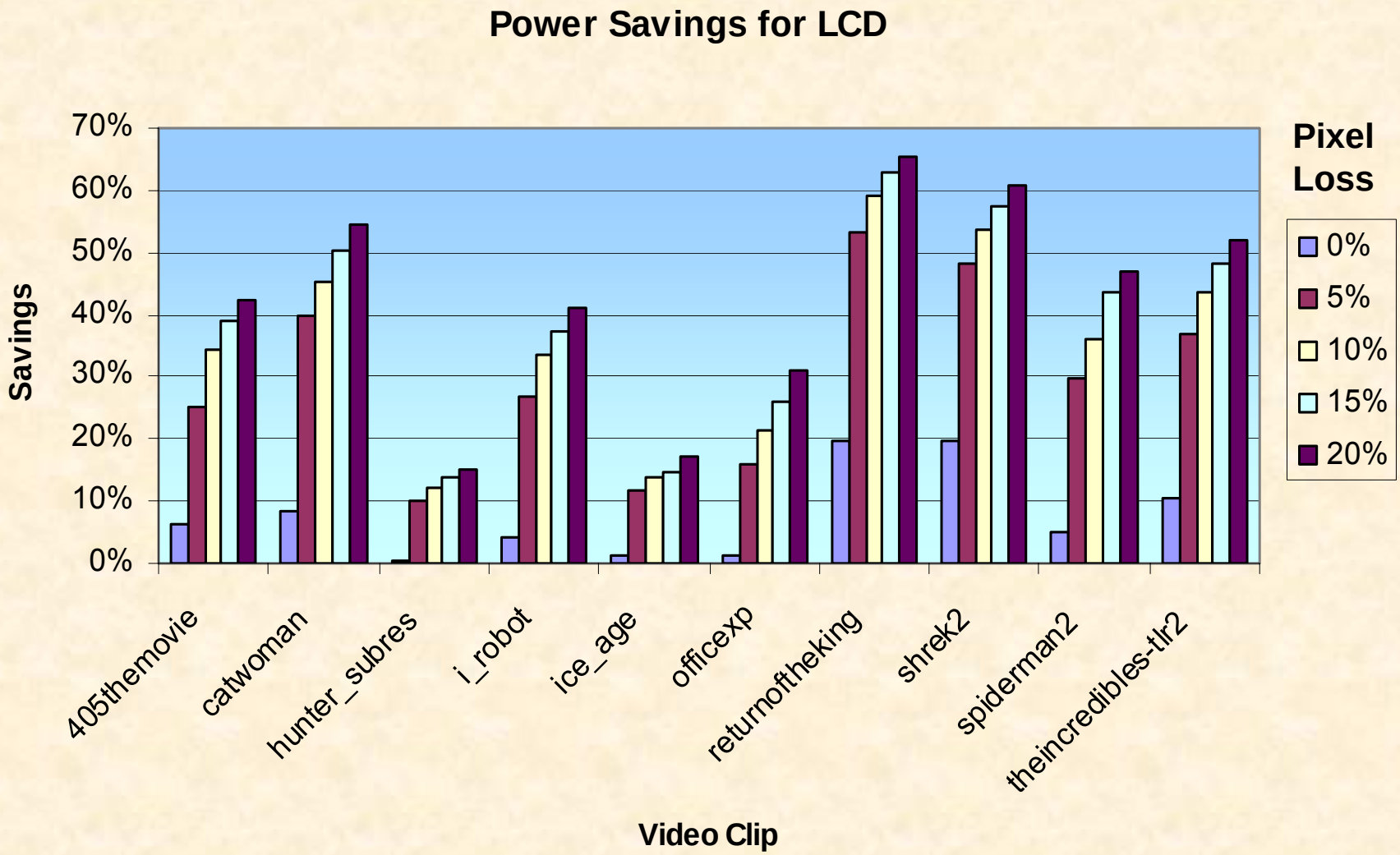
- Steps:
  - 1. Dim backlight
  - 2. Compensate image
- Side effect
  - Some clipped pixels



Quality Trade-offs

- Problems
  - Brightness / contrast adjustment may distort original image (saturated pixels, clipping)
- Trade-offs:
  - Lossless: limited power savings
  - Some quality loss: better savings
    - Few pixels of the image (whites) get clipped
- Works better for dark scenes
  - Not very well for bright ones
    - E.g. Ice Age (lots of snow)

Application Level: Results



Network Level

- Network card
  - 30% of overall energy (or even higher)
  - Power optimization challenging
    - Only option: low power mode
    - Few opportunities, due to streaming
      - IEEE 802.11 protocol

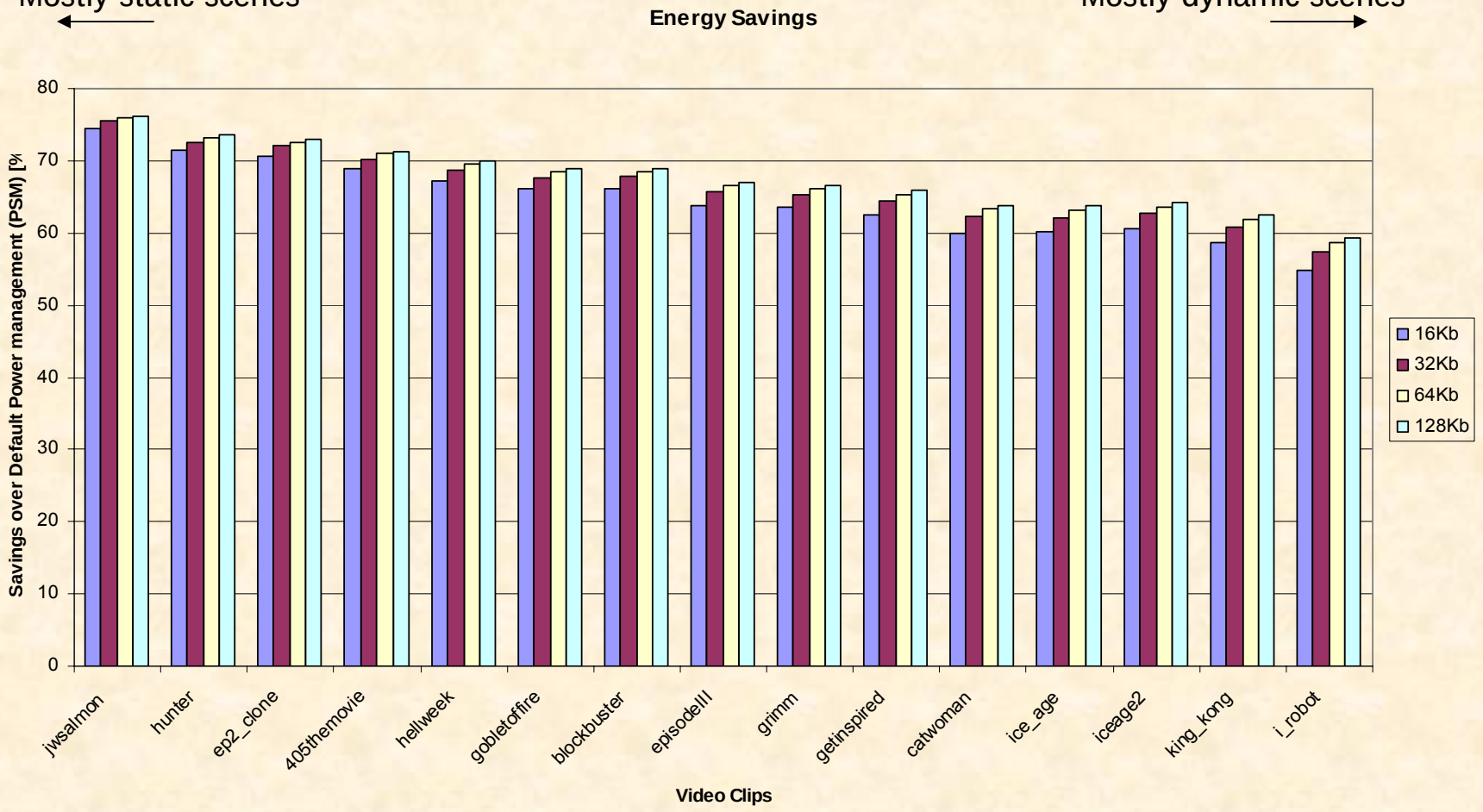
- We propose a new annotation-driven burst-type transmission that maximizes idle times
  - Between bursts network card -> low power mode
  - Improved energy savings for network interface

[ESTIMEDIA 2006]

Energy Savings

Mostly static scenes

Mostly dynamic scenes



Energy Savings and Drop Rates

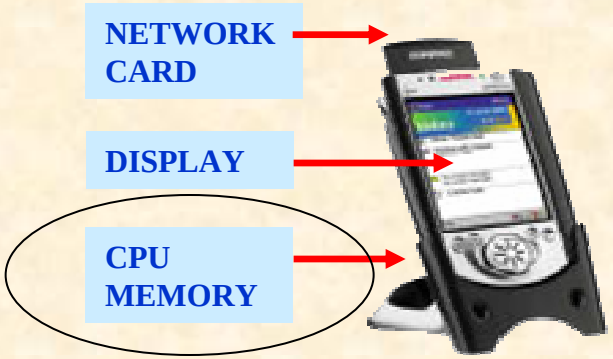
Video Clip	Energy Savings (%)				Package Drop (%)			
	16Kb	32Kb	64Kb	128Kb	16Kb	32Kb	64Kb	128Kb
catwoman	60.01	62.24	63.27	63.79	1.80	0.00	0.00	0.00
405themovie	68.95	70.27	70.96	71.31	4.32	0.50	0.00	0.00
blockbuster	66.20	67.77	68.55	68.95	0.00	0.00	0.00	0.00
ep2_clone	70.72	72.01	72.60	72.92	0.00	0.00	0.00	0.00
episodeIII	63.83	65.61	66.47	66.93	1.38	0.00	0.00	0.00
getinspired	62.50	64.38	65.34	65.82	4.49	0.00	0.00	0.00
grimm	63.50	65.29	66.20	66.65	0.87	0.00	0.00	0.00
hellweek	67.21	68.75	69.50	69.88	1.59	0.00	0.00	0.00
gobletoffire	66.13	67.72	68.51	68.93	1.47	0.00	0.00	0.00
hunter	71.43	72.62	73.20	73.50	0.00	0.00	0.00	0.00
iceage2	60.68	62.68	63.68	64.18	2.67	0.00	0.00	0.00
ice_age	60.19	62.13	63.25	63.78	5.66	0.00	0.00	0.00
i_robot	54.80	57.28	58.60	59.21	8.75	0.00	0.00	0.00
jwsalmon	**74.55**	**75.50**	**75.97**	**76.18**	**0.00**	**0.00**	**0.00**	**0.00**
king_kong	58.64	60.80	61.91	62.45	2.00	0.29	0.00	0.00
meeting_agnus	72.56	73.73	74.28	74.56	0.28	0.00	0.00	0.00
officexp	59.78	61.92	63.02	63.60	10.17	0.00	0.00	0.00
returnoftheking	65.13	66.85	67.67	68.10	1.11	0.00	0.00	0.00
sallyangela	58.31	60.82	61.92	62.46	0.14	0.00	0.00	0.00
vaio	69.19	70.66	71.33	71.66	0.00	0.00	0.00	0.00
saturday	66.84	68.36	69.11	69.51	1.24	0.00	0.00	0.00
shrek2	**55.16**	**57.44**	**58.76**	**59.41**	**22.99**	**0.57**	**0.00**	**0.00**
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
spiderman2	54.49	57.00	58.32	58.95	10.01	0.00	0.00	0.00
incredibles	56.22	58.61	59.84	60.44	9.55	0.00	0.00	0.00
timescape	71.87	73.07	73.63	73.92	0.61	0.00	0.00	0.00
underground	70.11	71.33	71.96	72.29	0.00	0.00	0.00	0.00
wronglanding	68.91	70.37	71.07	71.43	1.37	0.00	0.00	0.00
zeroonezero	60.17	62.24	63.32	63.83	4.87	0.00	0.00	0.00

Static scenes

Dynamic scenes

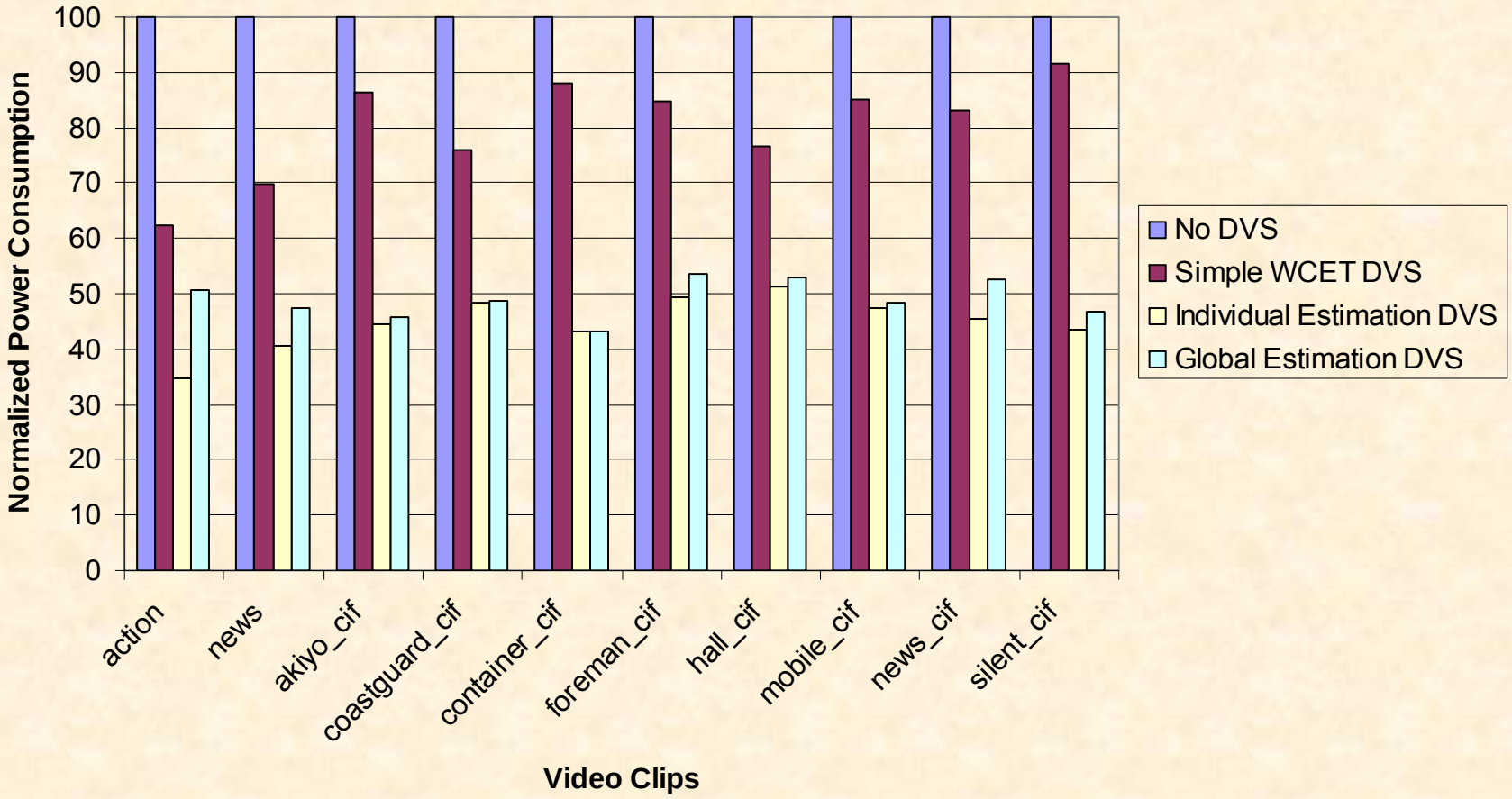
Hardware Level

- CPU/Memory
  - 30% of overall energy
  - Power optimization challenging
    - Variations on data processed
- Possible architecture level knobs
  - Cache configuration
  - Dynamic Voltage Scaling (DVS)
- We propose a new annotation-based DVS technique
  - Preprocess and annotate stream
  - Estimate frame decoding time from frame size/type
  - More aggressive DVS
    - Frequency scaling only (on iPAQ)



[ISPDC 2006]

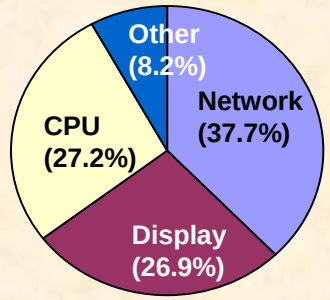
Hardware Level: Results



- Simple WCET: same frequency for the entire clip
- Curve fitting: for each clip (individual) or for all clips (global)

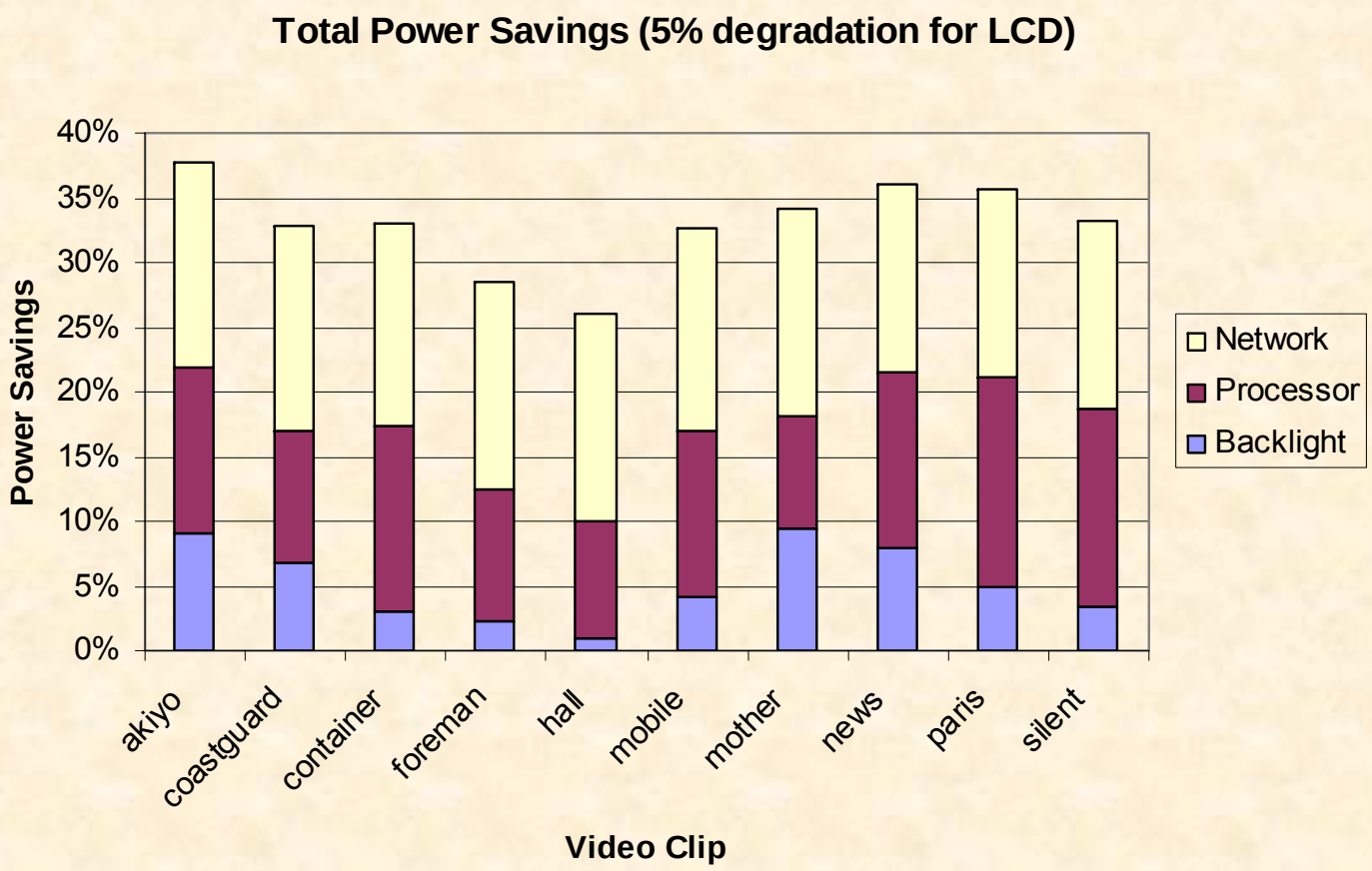
Annotation Integration

- Video clips:
  - Multimedia community
- Annotations:
  - CPU Level: Frame decoding
  - Network Level: Burst transmission
  - Application Level: Backlight scaling
- Independent Optimizations
  - Additive results
- Assumption:
  - 5% quality degradation for LCD
    - Unnoticeable on actual PDA



Energy Distribution (Before Optimization)

Integration Results



Power-quality Trade-offs

- Multimedia
  - Lossy compression
  - Allows quality of service trade-offs
    - Higher energy savings with minimal quality degradation
- Challenges
  - Good objective quality assessment
    - As close as possible to human subjective assessment

Quality Assessment for Videos

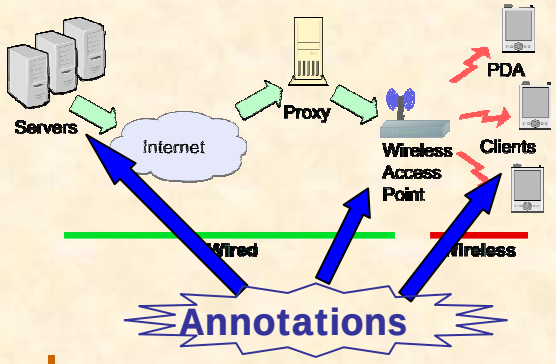
- Backlight scaling
  - Frame comparison before and after compensation
    - Clipped pixels -> quality decrease
  - Average for the entire clip => quality index for clip
- Frame decoding
  - More challenging: frame dropping (B frames)
  - Usually players display previous image:
    - Initial sequence: ABCD, C lost => ABBD
    - Compute quality index between each pair of frames
    - Average for entire clip => quality index for clip

Cross-Layer Trade-offs: ‘coastguard’

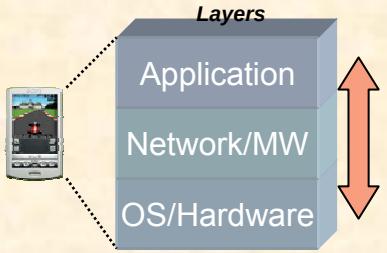
- Example: for Q=0.95
  - Backlight q=0.95, Processor q=1 => Savings=0.3*(0.31+0.38)=23%
  - Backlight q=1, Processor q=0.95 => Savings=0.3*(0+0.41)=13.6%
  - Almost 10% difference!

Conclusions

- New framework for streaming
  - Annotation-based
  - Content-aware optimizations
  - Annotations prove useful at all levels



- Power-quality trade-offs possible
  - Higher power savings
  - Minimal quality degradation
  - Cross-layer



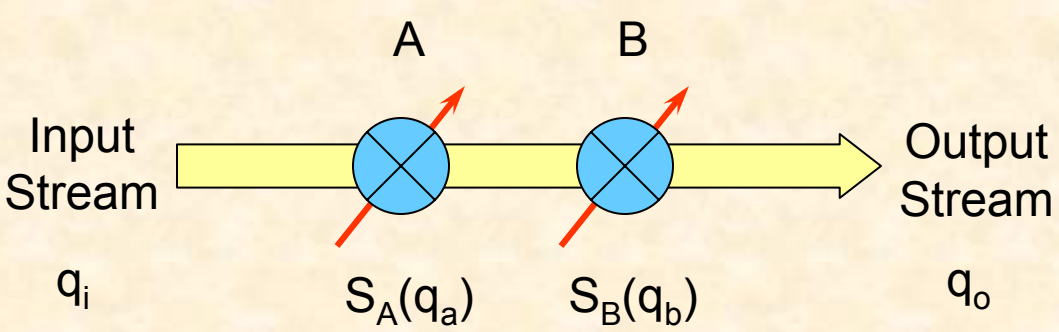
Partial Publications List

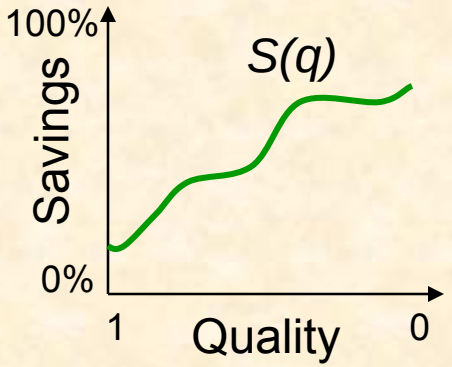
- *"Annotation Based Multimedia Streaming Over Wireless Networks",*
  R. Cornea, A. Nicolau, N. Dutt,
  Fourth IEEE Workshop on Embedded Systems for Real Time Multimedia, October 2006.
- *"Video Stream Annotations for Energy Trade-offs in Multimedia Applications",*
  R. Cornea, A. Nicolau, N. Dutt,
  International Symposium on Parallel and Distributed Computing, July 2006.
- *"Software Annotations for Power Optimization on Mobile Devices" ,*
  R. Cornea, A. Nicolau, N. Dutt,
  Design Automation and Test in Europe, March 2006.
- *"Power-aware Cross-layer Adaptation for Mobile Applications",*
  R. Cornea, M. Kim, K. Lee, G. Madl, S. Mohapatra, H. Oh, N. Dutt, A. Nicolau, N. Venkatasubramanian,
  New Initiatives Workshop (poster), Nov. 2005
- *"A Cross-Layer Approach for Power-Performance Optimization in Distributed Mobile Systems",*
  S. Mohapatra, R. Cornea, H. Oh, K. Lee, M. Kim, N. Dutt, R. Gupta, A. Nicolau, S. Shukla, N. Venkatasubramanian,
  International Parallel and Distributed Processing Symposium, April 2005.
- *"Managing Cross-Layer Constraints for Interactive Mobile Multimedia" ,*
  R. Cornea, S. Mohapatra, N. Dutt, A. Nicolau, N. Venkatasubramanian,
  Workshop on Constraint-Aware Embedded Software, IEEE RTSS, December 2003.
- *"Integrated Power Management for Video Streaming to Mobile Handheld Devices",*
  S. Mohapatra, R. Cornea, N. Dutt, A. Nicolau, N. Venkatasubramanian,
  ACM Multimedia, November 2003.
- *"ServiceFORGE: A Software Architecture for Power and Quality Aware Services",*
  R. Cornea, N. Dutt, R. Gupta, S. Mohapatra, A. Nicolau, C. Pereira, S. Shukla, N. Venkatasubramanian,
  SBCE Workshop at the International FME Symposium, September 2003.
- *"Distributed Multimedia Streaming in a Heterogeneous Environment",*
  R. Cornea, S. Mohapatra, N. Dutt, A. Nicolau, N. Venkatasubramanian,
  Concurrent Information Processing and Computing (invited talk), July 2003.
- *"A Model-Based Approach to System Specification for Distributed Real-time and Embedded Systems",*
  R. Cornea, S. Mohapatra, N. Dutt, R. Gupta, I. Krueger, A. Nicolau, D. Schmidt, S. Shukla, N. Venkatasubramanian,
  RTAS Workshop on Model-Driven Embedded Systems, May 2003.
- *"FORGE: A Framework for Optimization of Distributed Embedded Systems Software",*
  R. Cornea, N. Dutt, R. Gupta, I. Krueger, A. Nicolau, D. Schmidt, S. Shukla,
  International Parallel and Distributed Processing Symposium, April 2003
- *"Profile-based Dynamic Voltage Scheduling using Program Checkpoints in the COPPER Framework",*
  A. Azevedo, I. Issenin, R. Cornea, R. Gupta, N. Dutt, A. Veidenbaum, A. Nicolau,
  Design Automation and Test in Europe, March 2002.
- *"Architectural and Compiler Strategies for Dynamic Power Management in the COPPER Project",*
  A. Azevedo, R. Cornea, I. Issenin, R. Gupta, N. Dutt, A. Nicolau, A. Veidenbaum,
  International Workshop on Innovative Architecture, January, 2001.
- *"Architecture Exploration of Parameterizable EPIC SOC Architectures",*
  A. Halambi, R. Cornea, P. Grun, N. Dutt, A. Nicolau,
  Design Automation and Test in Europe, March 2000.
- **Three Patents (in process)**

Thank You!

Quality Composition Analysis

- Problem: multiple techniques at system level (A, B)
  - How to represent final quality (q_o) and savings?



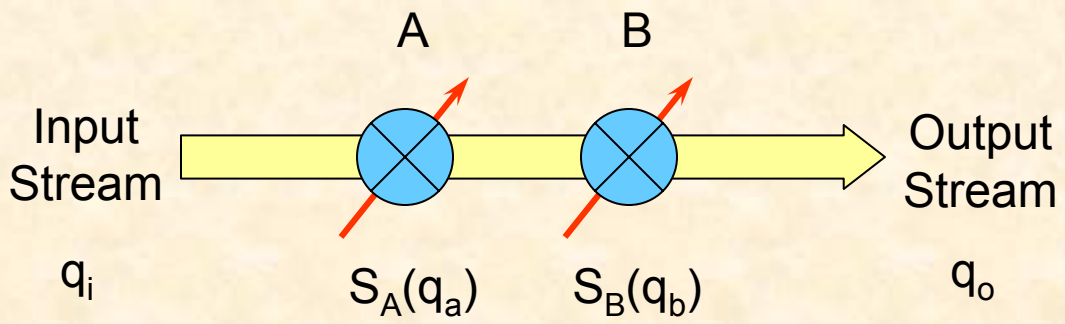


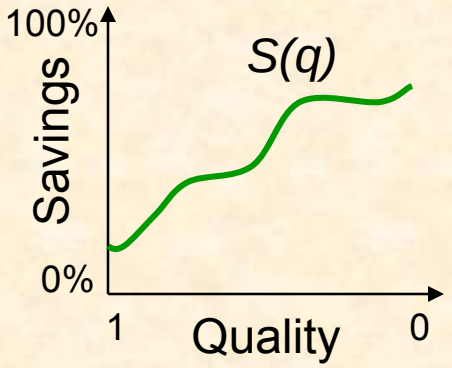
- Assumption: techniques <u>are independent</u>
  - ⇒ Each quality index contributes as a factor ($q_a * q_b$)

    $Q=q_a*q_b$, where Q = overall quality factor, $q_i=0..1$
  - ⇒ Savings are additive ($S_A + S_B$)

    $S=S_A(q_A)+S_B(q_B)$

Cross-Layer Trade-off Analysis





- Optimization problem
  - Maximize $S=S_A(q_A)+S_B(q_B)$
  - While maintaining $Q=q_a*q_b$ high
- Users may prefer some quality degradations
  - In general: $Q=q_a^{\alpha}*q_b^{\beta}$

  α, β = relative importance of A,B (α=β=1 if equal importance)
- In general

  $Q=q_1^{p1}*q_2^{p2}*\ldots*q_n^{pn}$, $S=S_1(q_1)+S_2(q_2)+\ldots+S_n(Q_n)$

Application Level: Summary

- Demonstrated the use of annotations for characterizing video streams
- Up to 60% LCD power savings possible
  - With minimal quality degradation
  - Translates into around 17% total power saved
- Small savings possible even with no QoS degradation
  - Movies with predominantly dark scenes

Network Level: Summary

- Improved power management for network interface
  - 60-75% savings over the default power management in IEEE 802.11 (PSM)
- Annotation prove useful to improve accuracy
  - At server/access point
    - Bursts based on consumption rate
  - At client side
    - Buffer management
  - Better power savings, zero or minimal frame loss
- Improved packet drop rate compared with other approaches

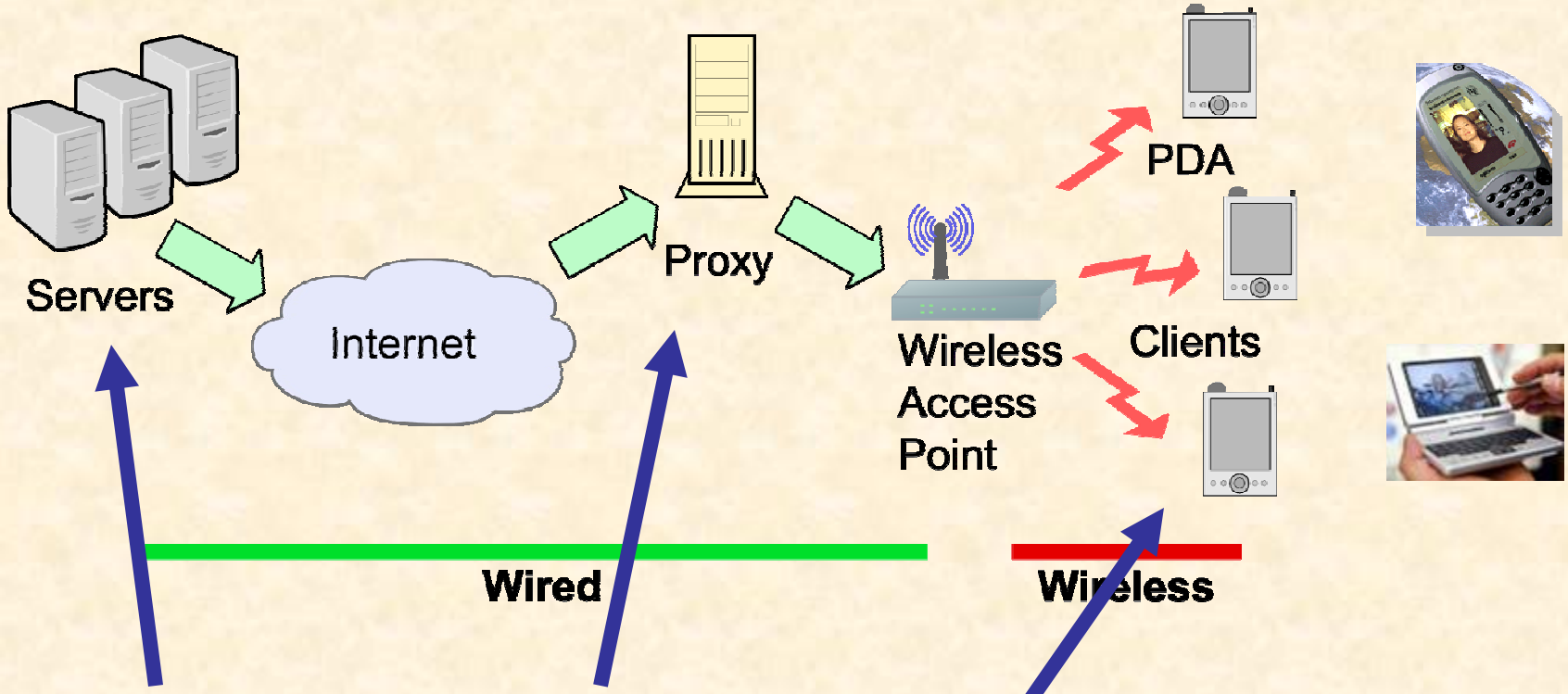
Hardware Level: Summary

- Annotations
  - Useful for predicting runtime behavior
  - Applied for estimating frame decoding time
  - More aggressive DVS
- Good results for similar video clips
  - ~50% over no DVS
  - ~40% over simple DVS

Multimedia on Mobile Devices

- Portable devices have limited resources, due to their modest sizes and weights
  - CPU processing power, memory
  - Smaller displays
  - Limited battery life
- Multimedia applications
  - Computation-intensive
  - Communication-intensive
  - Quality of Service
- *Multimedia application place a heavy burden on already constrained devices*

System Architecture



- Annotations can be inserted at either
  - Server node
  - Proxy node
- Annotations are used at the client end