Fast Hybrid Simulation for Accurate Decoded Video Quality Assessment on MPSoC Platforms with Resource Constraints

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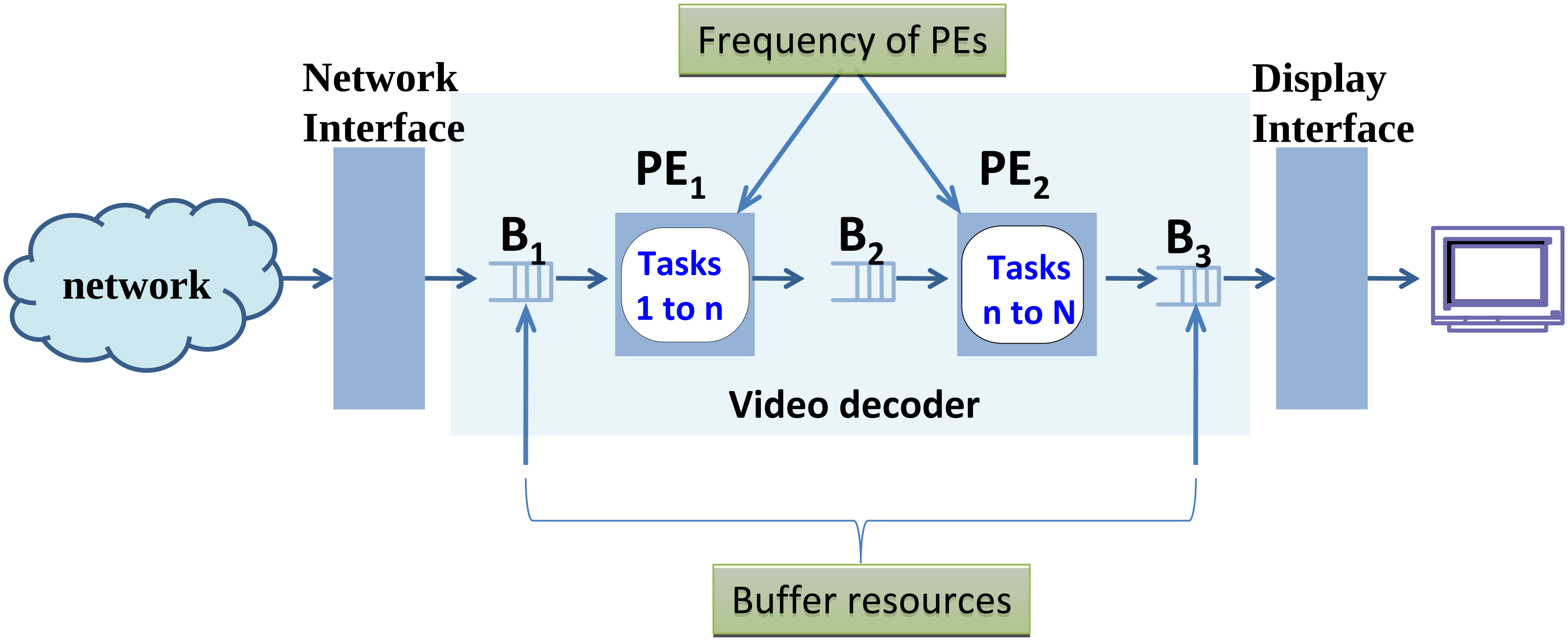
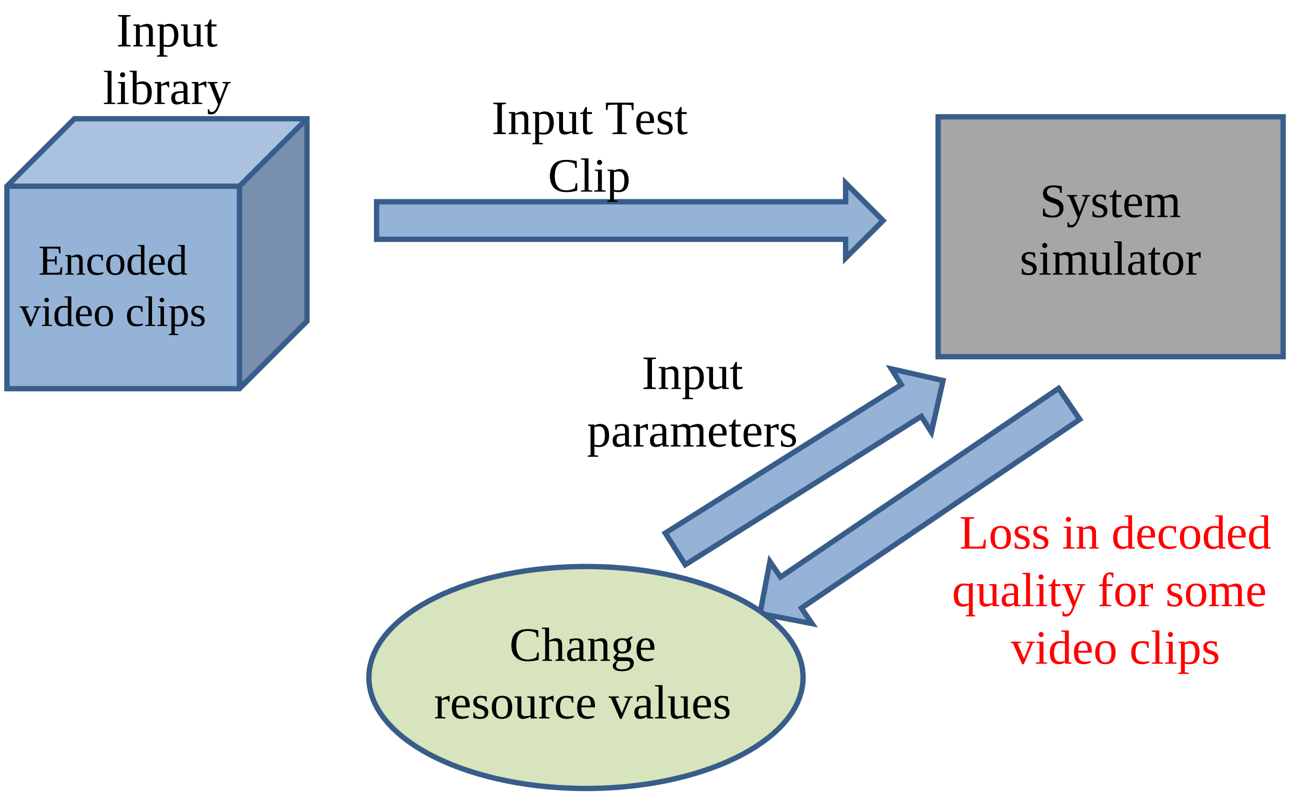
Motivation (Typical MPSoC architecture for video decoders)



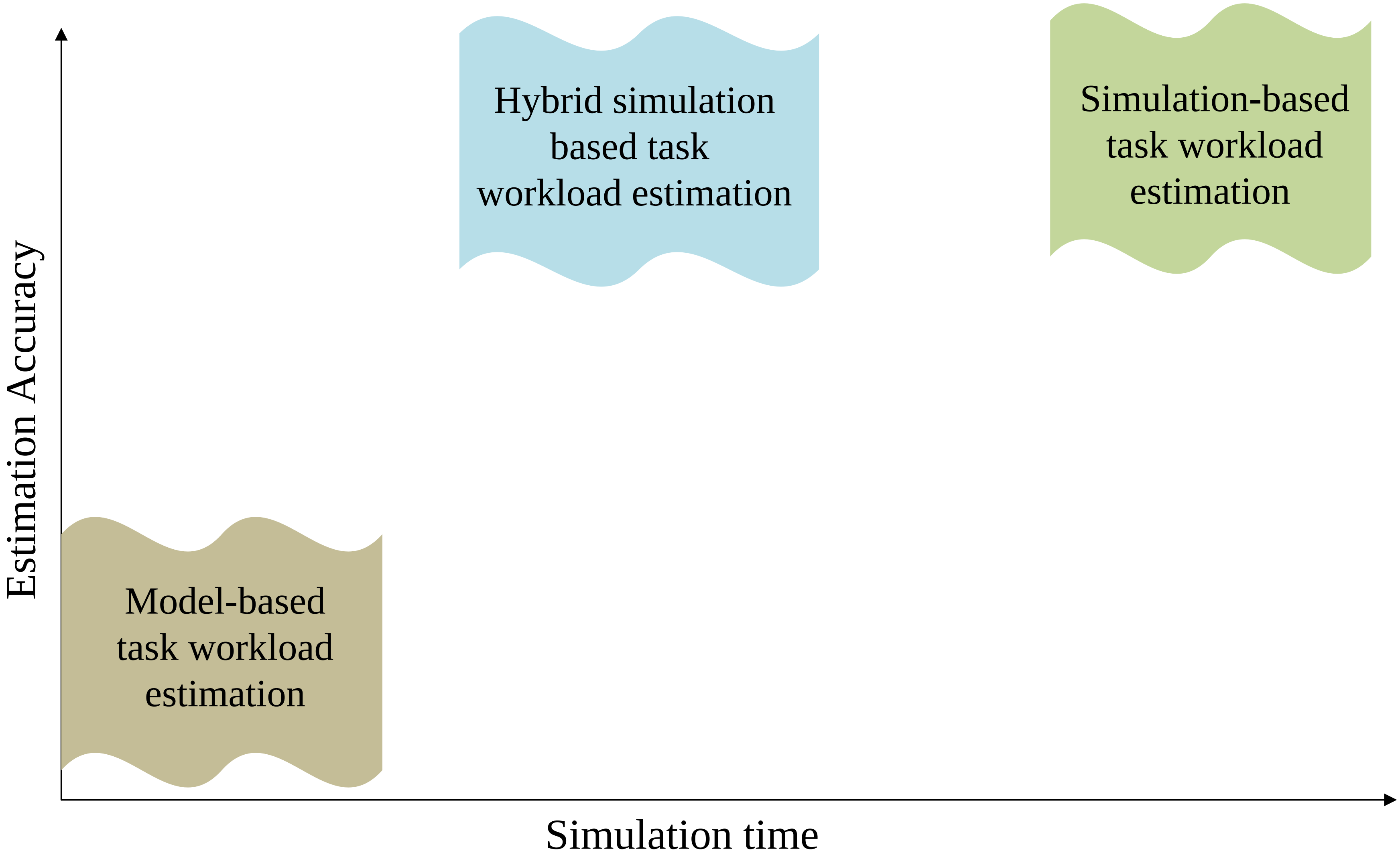
- Mobile devices with video decoders have resource (frequency, buffer etc) constraints
- Resources can be determined based on the output quality requirement
- Necessity for an efficient framework to explore the trade-off between resources and display quality

Motivation (Conventional method - Design space exploration of resources for no loss in quality)



- System should satisfy the “no quality loss” constraint for all test video clips
- A model of the system running a decoder application is used in the system simulator
- All video clips simulated to obtain decoder task workload values
- High simulation time!!

Motivation (Reducing simulation time)



Organization

- Related Work
- Overview of hybrid simulation-based quality assessment framework
- MPEG2/MPEG4 workload models
- Frame discard strategy
- Experimental results

Related Work

- Very little work on studying the trade-offs between scarce system resources (frequency and buffer) and decoded video quality important for mobile devices
- Yanhong et al. [1] investigate trade-offs between quality of MPEG-4 decoded video and processor frequency

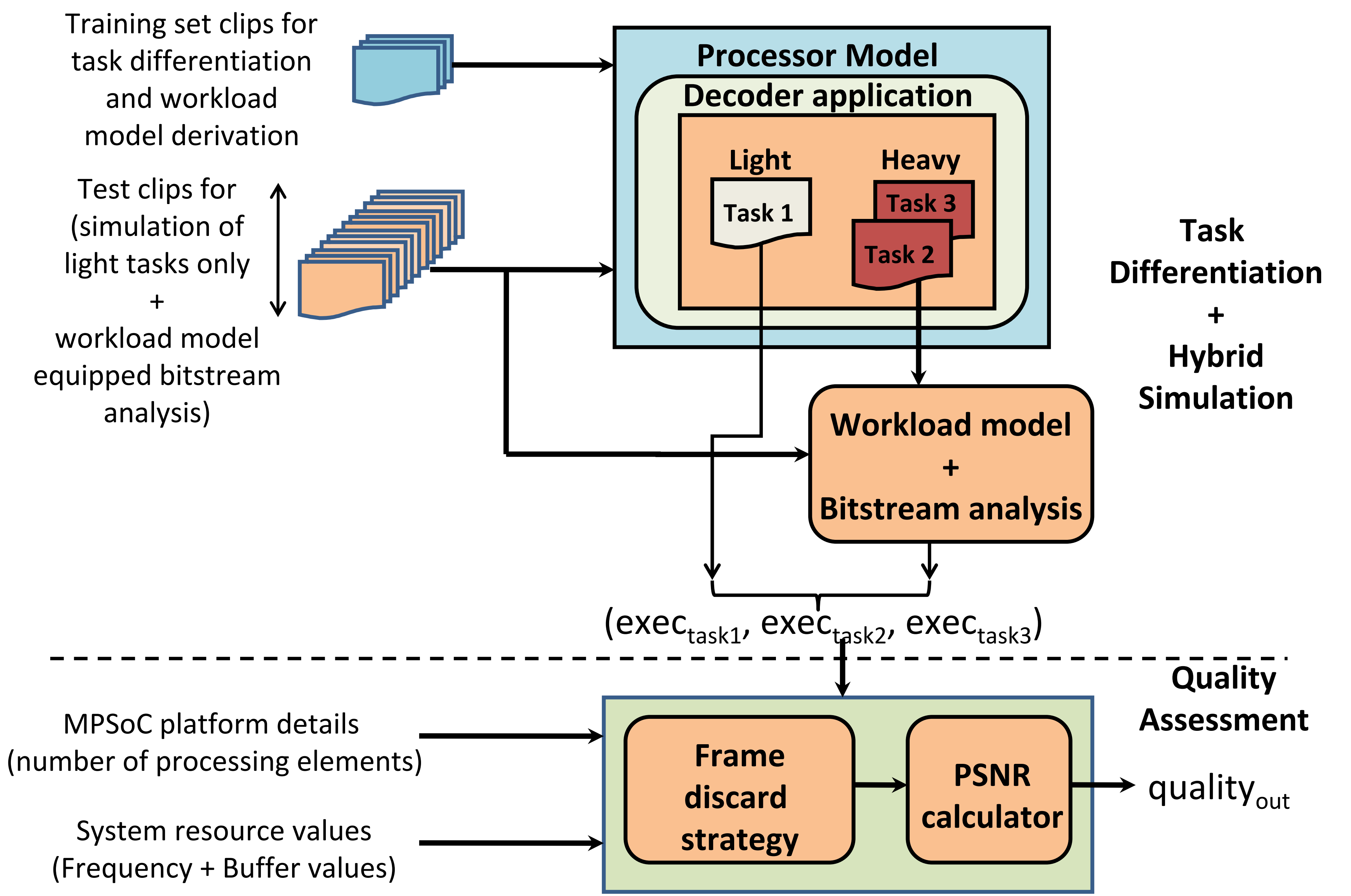
  - Use expensive simplescalar simulations to find task workload values
- Koumaras et al. [2] propose an end-to-end video quality prediction framework with packet losses in a network transmission scenario

  - Cannot be adapted to mobile devices because PSNR value estimation is not accurate

[1] L. Yanhong, S. Chakraborty, O. W. Tsang, A. Gupta, and S. Mohan. **Workload characterization and cost-quality tradeoffs in mpeg-4 decoding on resource-constrained devices**. In *3rd IEEE Workshop on Embedded Systems for Real-Time Multimedia (ESTIMedia), 2005.*

[2] H. Koumaras, C. H. Lin, C. K. Shieh, and A. Kourtis. **A framework for end-to-end video quality prediction of mpeg video**. *Journal of Visual Communication and Image Representation,* 21(2):139–154, 2010.

Overview of our framework



Step 1 - Task Differentiation

- Tasks in a decoder application are differentiated based on a **lightness** property of the tasks (using training set video clips)

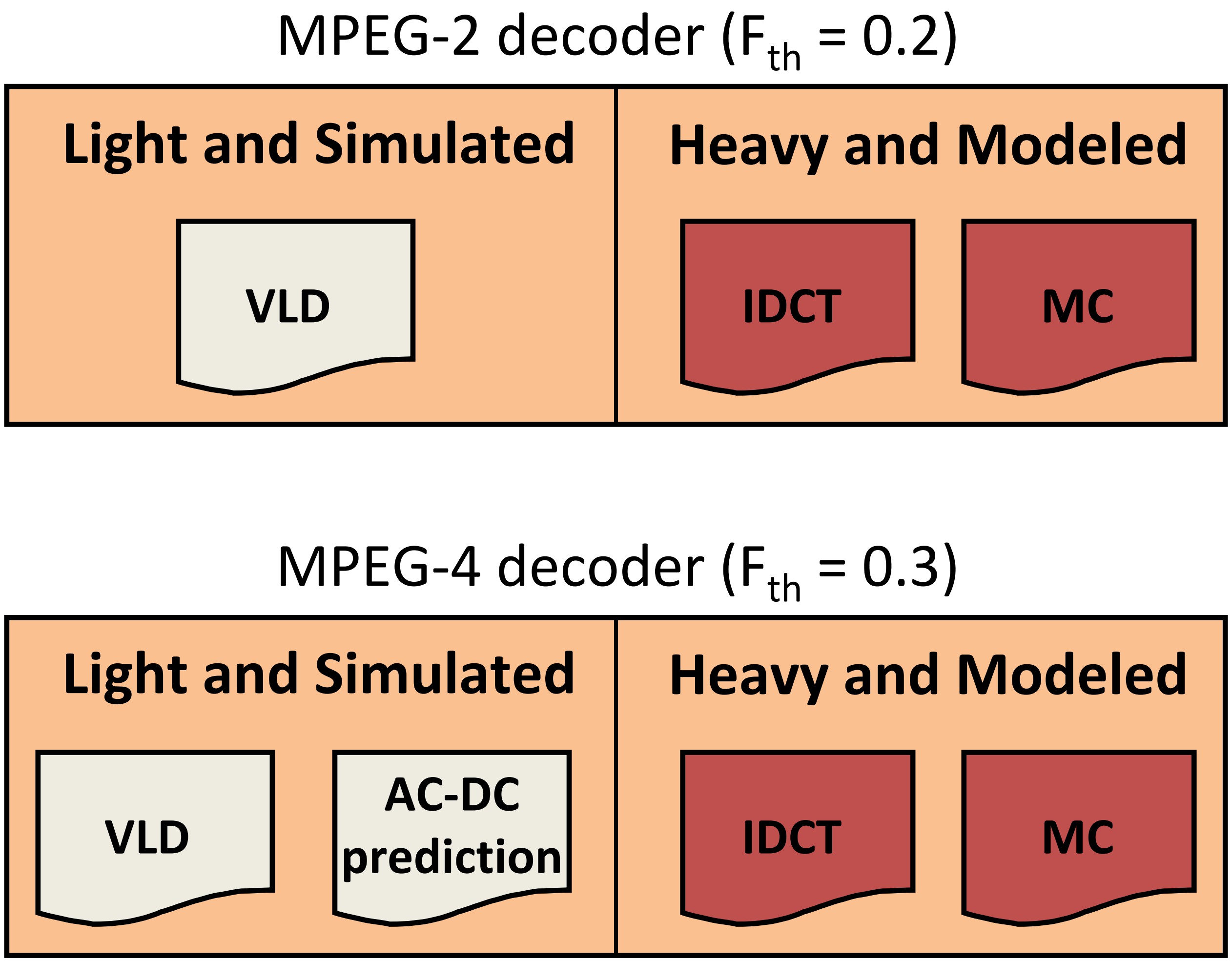
- For a task t_k, ;k where $1 \cdot k \cdot N_T$, **lightness** property is determined by

$$T_k \cdot F_{th} \text{ £ } T_{tot}$$

- Light tasks and other tasks which cannot be accurately modeled are simulated

- Accurate task workload models are derived for the remaining tasks

MPEG-2/MPEG-4 decoder task differentiation



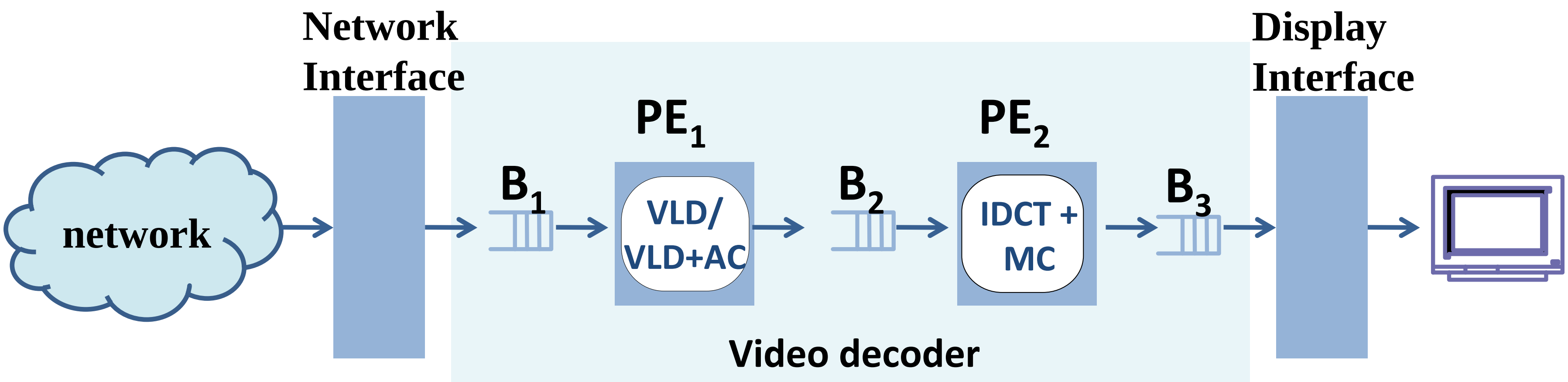
Step 2 - Hybrid Simulation

- Workload of heavy tasks (IDCT+MC for both MPEG-2 and MPEG-4 decoder) from Step 1 are estimated by extracting certain easily obtainable parameters from the video stream

- Accurate workload models are used for IDCT and MC (accuracy measured in terms of a **frame drop deviation** condition)

- Workload of light tasks from Step 1 are estimated by simulation as deriving accurate workload model is difficult

Frame Drop Deviation (FDD)



B_1 – Input buffer, **B_2** – Intermediate buffer, **B_3** - Playout buffer

- $b_{sim}(t) = r_{f1} + B\_bot_{sim}$ and $b_{model}(t) = s_{f2} + B\_bot_{model}$, ; t
  r_{f1} – r no. of MBs of (f1)-th frame at the top of the buffer and 0 ‰ r ‰ FSIZE
  s_{f2} has the same interpretation as r_{f1}

- According to FDD, everytime a buffer overflow occurs, FDD = 0 => |f1 – f2| = 0 => f1 = f2

Workload model for heavy tasks in MPEG-2/MPEG-4

- Video clips from training set used to derive the workload models
- Workload models were developed for portable ISA (PISA).
- VLD task workload **accuracy** is difficult to achieve by using a model in both MPEG-2 and MPEG-4. AC-DC prediction workload accuracy is also difficult to attain in MPEG-4.

MPEG-2 MC workload model

- MC workload depends on 6 parameters of the MPEG-2 frame namely

  1) Y component's x-dimension is HALF-PIXEL

  2) Y component's y-dimension is HALF-PIXEL

  3 & 4) U or V component's x and y-dimension is HALF-PIXEL

  5) forward or backward motion compensation is required

  6) motion compensation window is 16x8 or 16x16

- Depending on the frame type, the MC routine is called with different parameters

- Look-up table with 64 processor workload values is used to model the MC workload

  $Workload_{MC}$ = LUT(x), where x is a 6-bit value

MPEG-2 IDCT workload model

- IDCT workload depends on the number and position of non zero IDCT coefficients in the 8x8 block structure of MB

- To adhere to FDD condition, certain shortcut conditions of fast IDCT implementations are also taken into consideration

- The IDCT workload model proposed is

  Workload_i = basis_i + ® £ n_sig_i - ¯ £ scnt_i, ; i

  Workload_{IDCT} = $\sum_{\iota}$ Workload_i, 1 · i · 6

- From training set simulations
  basis_i = 1965/1852/708/595
  ® = 113 and ¯ = 143

Frame discard strategy

- Multimedia frames are required to be discarded when the resources are insufficient to process them
- Frame discard strategy – Simple mechanism of dropping entire frame if one incoming MB cannot be accommodated in the buffer
- Dropped frames are replaced by previous accepted frames

Frame discard strategy (...contd)

- Rule 1: An I-frame drop is followed by drop of an entire group of pictures (GOP). No. of drops will be a minimum of GOP length
- Rule 2: A P-frame drop is followed by drop of the subsequent frames in the GOP. No. of drops will depend on the position of P-frame in the GOP
- Rule 3: A B-frame drop does not require any other frame drop
- Rule 4: A frame is dropped if any of its MBs causes overflow or it is dependent on a previously dropped frame

PSNR calculation

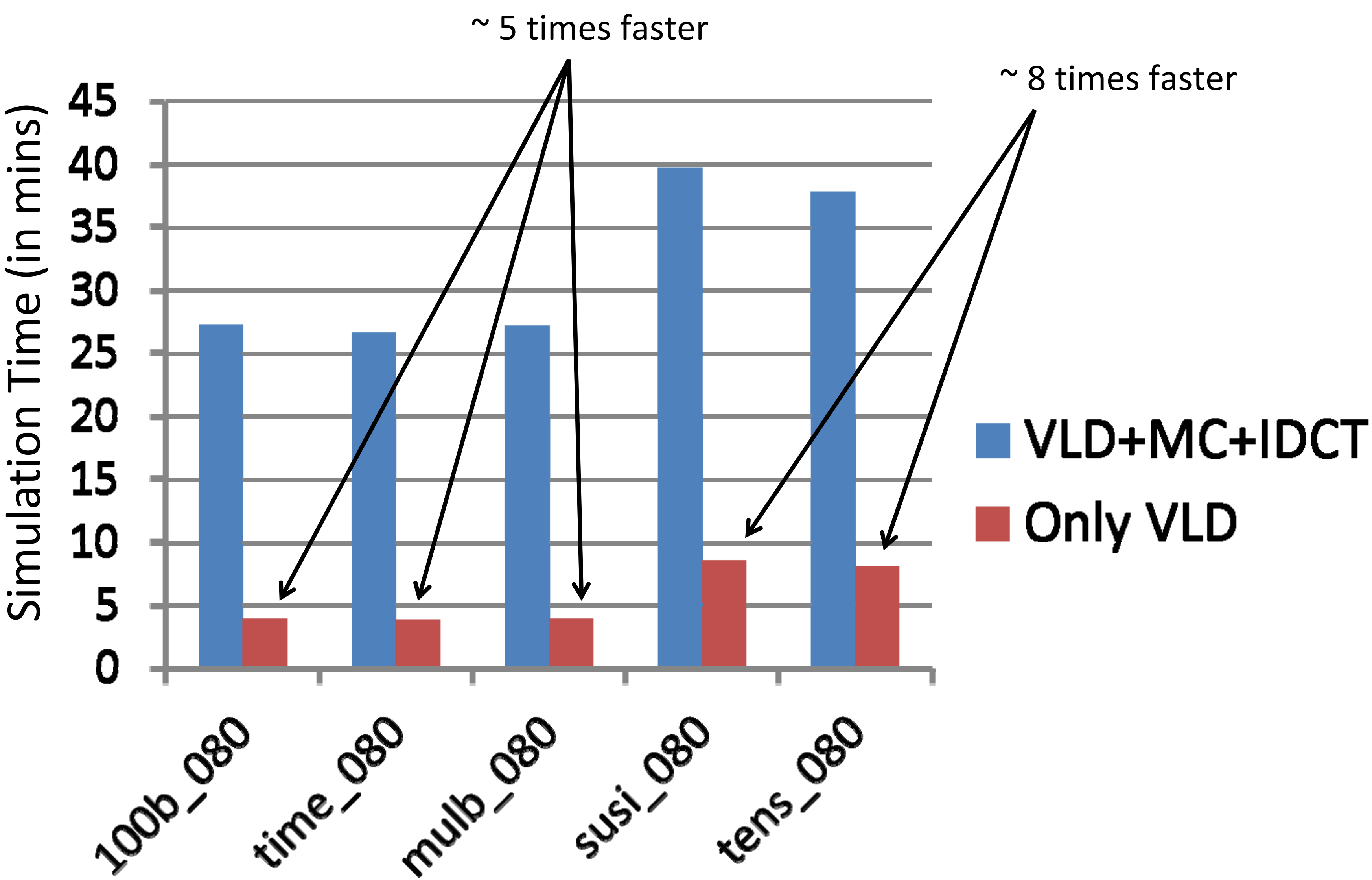
- A difference based PSNR (quality metric) is calculated as the original video frames are not available
- Noise – Mean square error (MSE) between the actual pixel values of dropped frame and pixel values of last accepted frame in display order
- PSNR value calculated using

$$psnr = 10 \times log_{10} \frac{(255 \times 255)}{\frac{(MSE\_r + MSE\_g + MSE\_b)}{(3 \times N_{tot} \times W \times H)}}$$

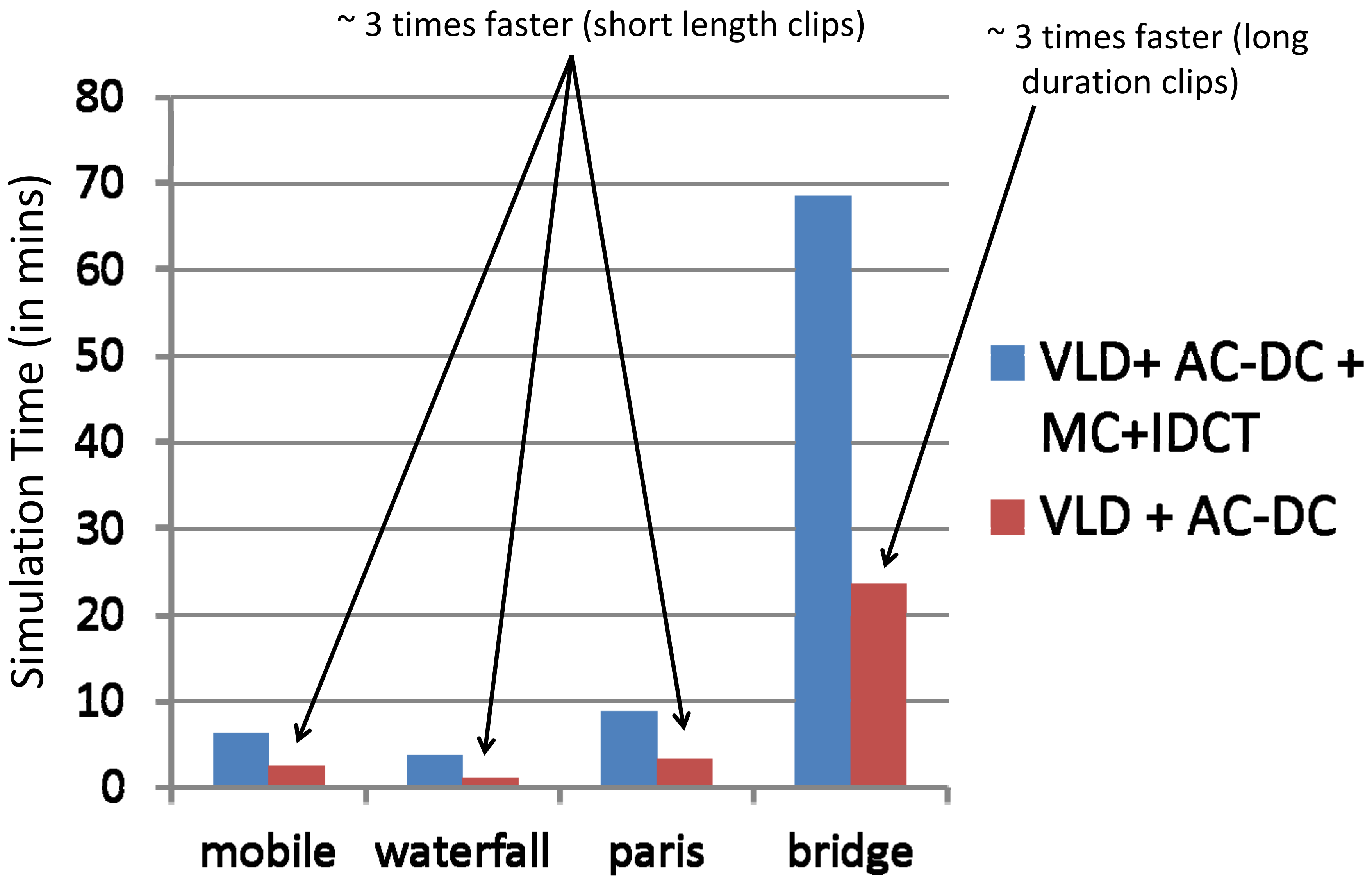
$$(MSE\_r)_n \quad = \quad \sum_{w=0}^{W-1} \sum_{h=0}^{H-1} \left(r_d(h,w,n) - r_c(h,w,n)\right)^2$$

$$MSE\_r \; = \; \sum_{n=0}^{N_{drop}-1} (MSE\_r)_n$$

Experimental Results
(Speed of Hybrid Simulation for MPEG-2)



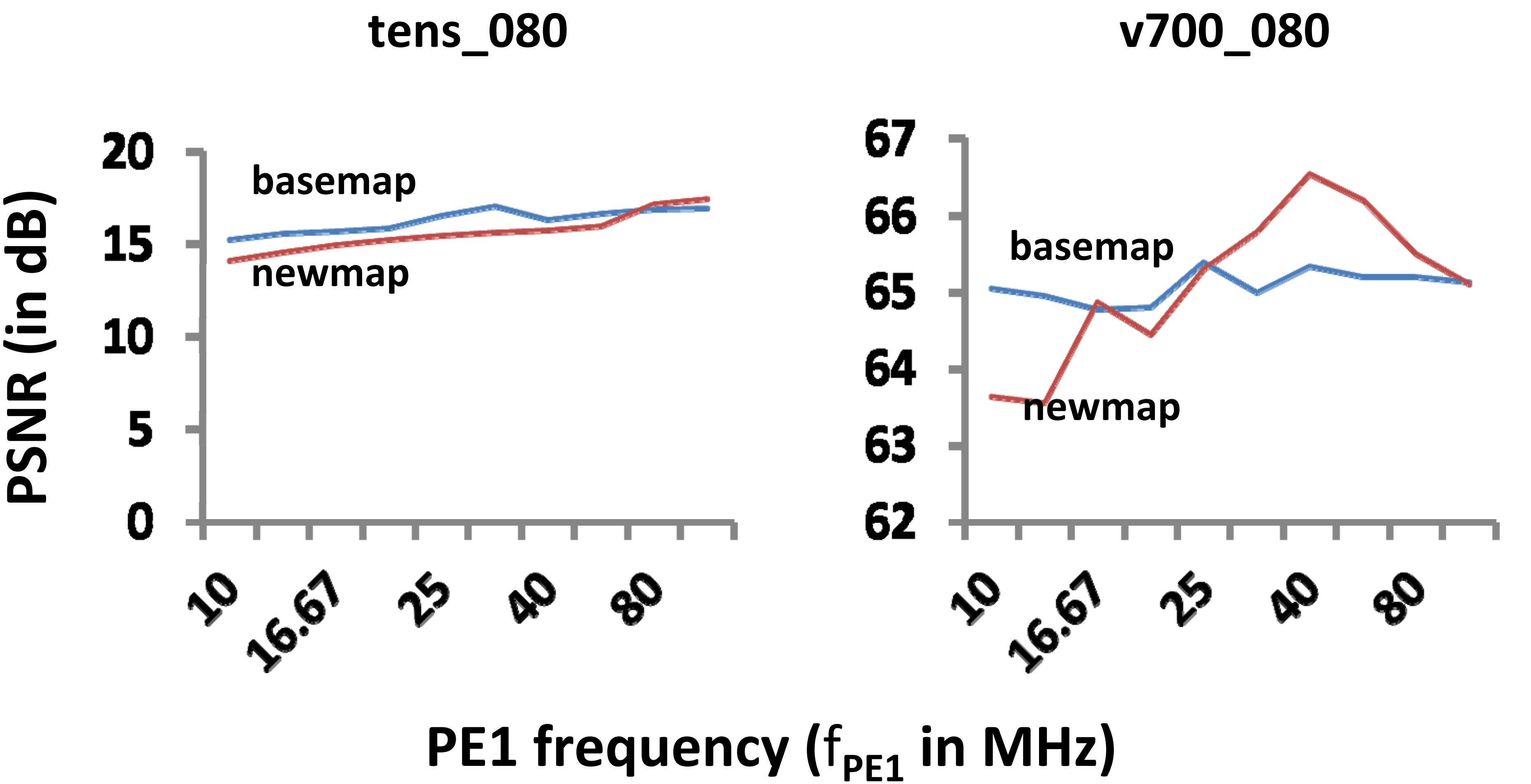
Experimental Results
(Speed of Hybrid Simulation for MPEG-4)



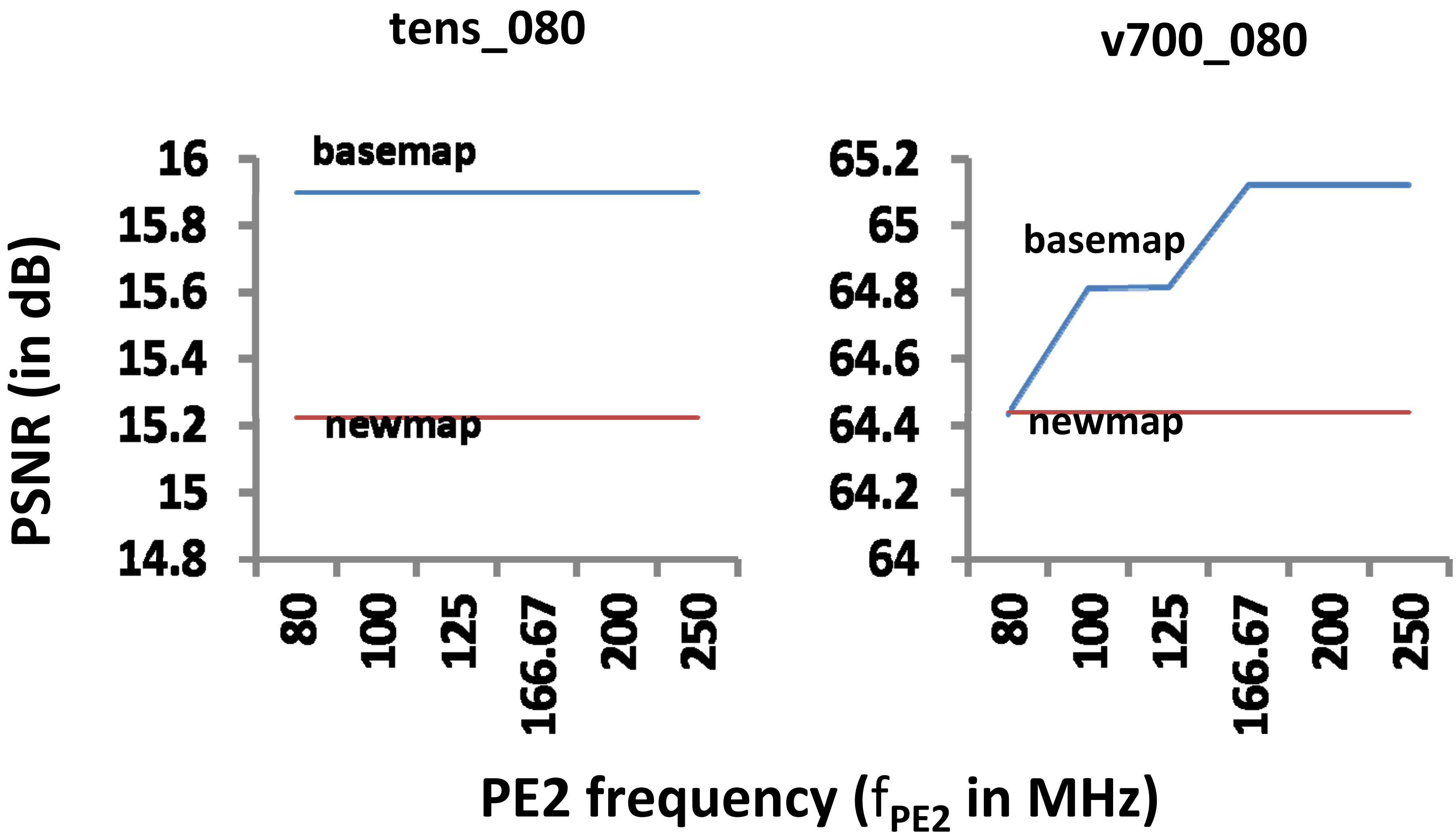
Experimental Results (Quality Estimation Accuracy)

- PSNR values obtained using model-based workload values were verified using simulation-based workload values
- PSNR values computed for 1500 resource combinations of f_{PE1}, f_{PE2}, B_1 and B_2
- PSNR values found for the *basemap* as well as *newmap* task mapping configurations
- *basemap* – 98% accuracy for motion video clips. Only § 0.3% deviation in PSNR values for the remaining 2%. 100% accuracy for the still videos.
- *newmap* – 100% accuracy in PSNR estimation for all clips

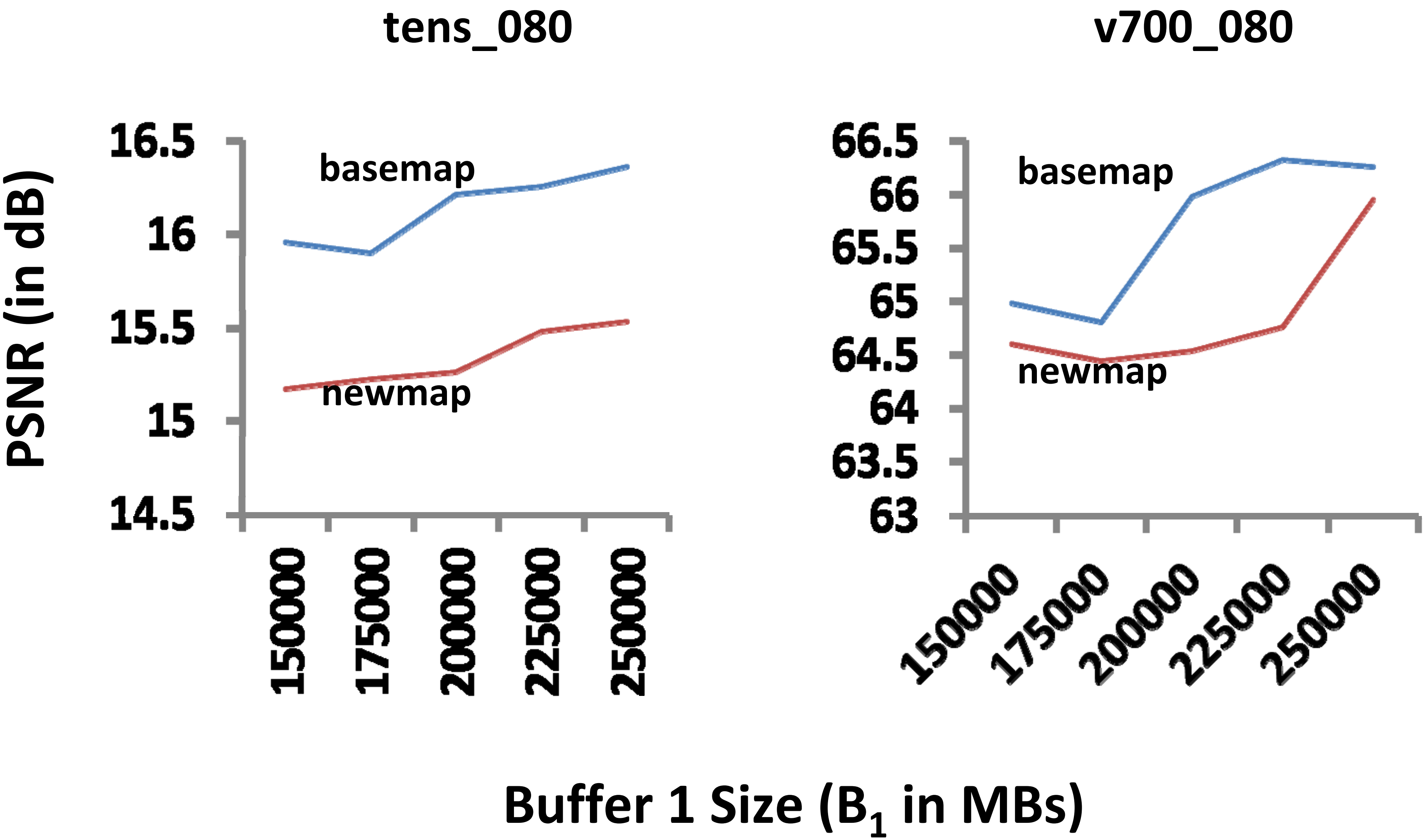
Experimental Results (PSNR vs f_{PE1} trade-off)



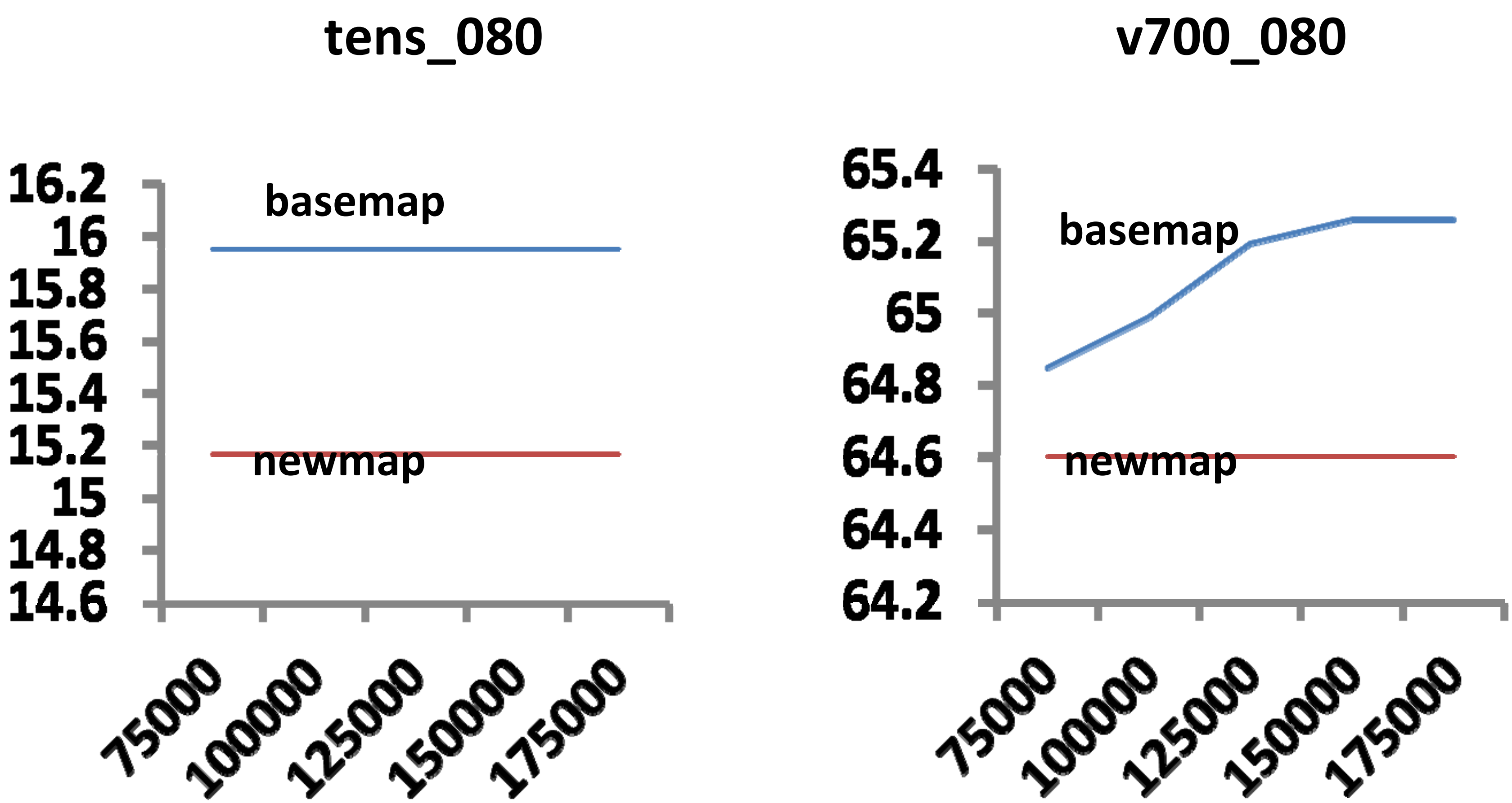
Experimental Results (PSNR vs f_{PE2} trade-off)



Experimental Results (PSNR vs B_1 trade-off)



Experimental Results
(PSNR vs B_2 trade-off)



PSNR (in dB)

Buffer 2 Size (B_2 in MBs)

Concluding Remarks

- **Central focus**:

  To devise a hybrid simulation strategy in order to enable the system designers to rapidly arrive at quantitative estimates of quality degradations for video clips in the context of resource constraints

- Framework also very useful to understand the non-trivial influences of system resources on the quantitative quality degradations

- Can be used to quickly estimate optimal points in resource space for desired quality

- Influence of other components in the framework such as frame discard strategy on the quality estimate can be studied rapidly