Analysis and Modeling of MPEG-4 and H.264 Multi-Layer Video Traffic

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Outline

1. Background
   - Motivation
   - Preliminaries
   - Challenges & Current Status
2. Our Work
   - Modeling single-layer video traffic
   - Modeling multi-layer video traffic
   - Model accuracy study

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Importance of Traffic Modeling

Importance

- Properly allocate network resources
- Evaluate protocols and effectively design networks
- Use as traffic descriptor to achieve certain Quality of Service (QoS) requirements
- Analyze and characterize a queue or a network

Goals of Traffic Modeling

Goals

- Capture the characteristics of video frame size sequences
  - The marginal probability density function (PDF) of frame sizes
  - The autocorrelation function (ACF) of video traffic
- Accurately predict network performance
  - Buffer overflow probabilities
  - Temporal burstiness

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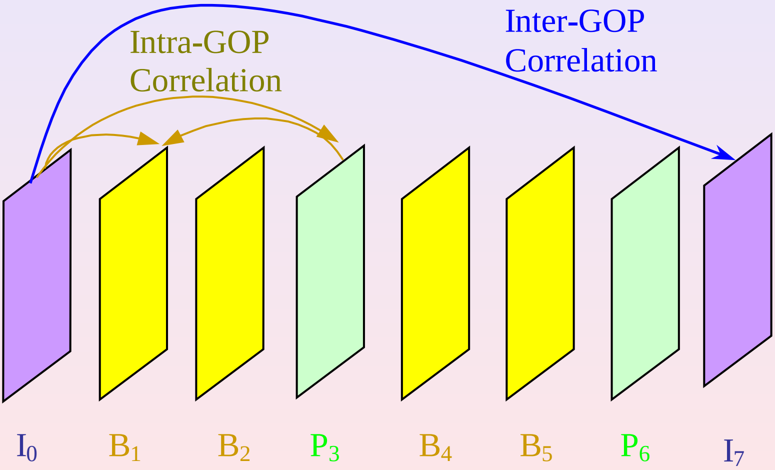
Group of Pictures



Inter- and Intra-GOP Correlation

Definition

1. Inter-GOP correlation is the correlation among various GOPs, which is well characterized by the ACF of the I-frames.
2. Intra-GOP correlation is the correlation between P/B-frames and the I-frame in the same GOP.

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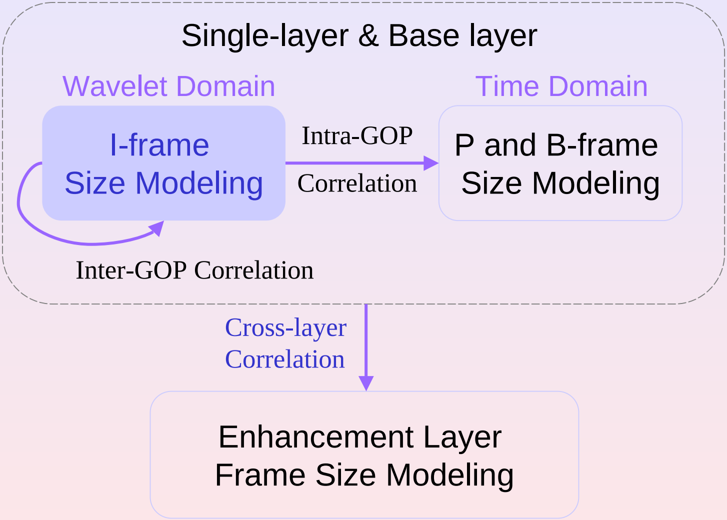
Challenges & Current Status

Challenges

- Coexistence of long range dependency (LRD) and short range dependency (SRD)
- Coexistence of inter- and intra-GOP correlation
- Strong cross-layer correlation in multi-layer video traffic
- Various PDF among I, P, and B-frame sizes distributions

Current Status

- Difficult to capture both LRD and SRD properties
- Little work has considered both inter- and intra-GOP correlation
- Most existing models only apply to single-layer video traffic
- Current multi-layer traffic models do not capture the cross-layer correlation


Single-layer & Base layer
Wavelet Domain
Time Domain
I-frame Size Modeling
Intra-GOP Correlation
P and B-frame Size Modeling
Inter-GOP Correlation
Cross-layer Correlation
Enhancement Layer Frame Size Modeling

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Wavelet Decomposition

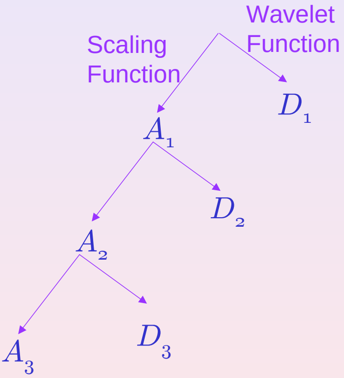


Figure: A typical wavelet decomposition

Wavelet Decomposition

- Wavelet decomposition can be simply considered as passing the original signal to a high-pass filter (wavelet function) and a low-pass filter (scaling function).
- Wavelet function generates the detailed coefficients $\{D_j\}$ and scaling function generates the approximation coefficients $\{A_j\}$, where j is the decomposition level.

Definition of Frame Sizes

Definition

Assuming that n is the GOP number,

1. $\phi^I(n)$ is the I-frame size of the n-th GOP.
2. $\phi_i^P(n)$ is the size of the i-th P-frame in the n-th GOP.
3. $\phi_i^B(n)$ is the size of the i-th B-frame in the n-th GOP.

For example, $\phi_3^P(10)$ represents the size of the third P-frame in the 10-th GOP.

Modeling I-Frame Sizes

Algorithm

1. Perform wavelet decomposition to I-frame sizes $\phi^I(n)$ till decomposition level J
2. Estimate the coarsest approximation coefficients $\{A_J\}$
3. Estimate the detailed coefficients at each level
4. Perform inverse wavelet transform to obtain the synthetic I-frame sizes

Modeling I-Frame Sizes

Analysis of Wavelet Coefficients

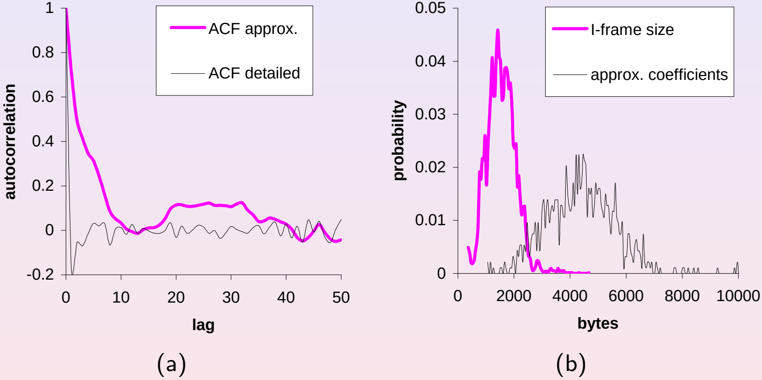


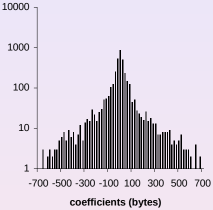
Figure: (a) The ACF structure of coefficients $\{A_3\}$ and $\{D_3\}$ in single-layer `Star Wars IV`. (b) The histogram of I-frame sizes and that of approximation coefficients $\{A_3\}$ in the same sequence.

Modeling I-Frame Sizes

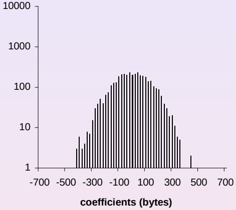
Estimation of Wavelet Coefficients

- Estimate the coarsest approximation coefficients $\{A_J\}$:
  - Prior work uses independent random Gaussian or Beta variables
  - Our model uses dependent random variables with marginal Gamma distribution
- Estimate detailed coefficients $\{D_j\}$ at each level:
  - Prior work uses i.i.d. Gaussian random variables
  - Our model uses i.i.d. mixture Laplacian random variables

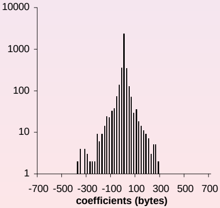
Modeling I-Frame Sizes
Detailed Coefficients Estimates



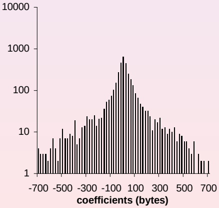
(a) Actual



(b) Gaussian



(c) GGD



(d) Mix-Laplacian

Modeling I-Frame Sizes
Performance Comparison

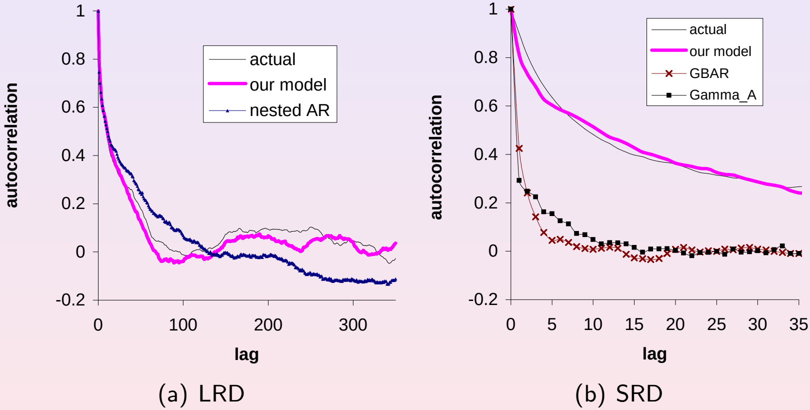
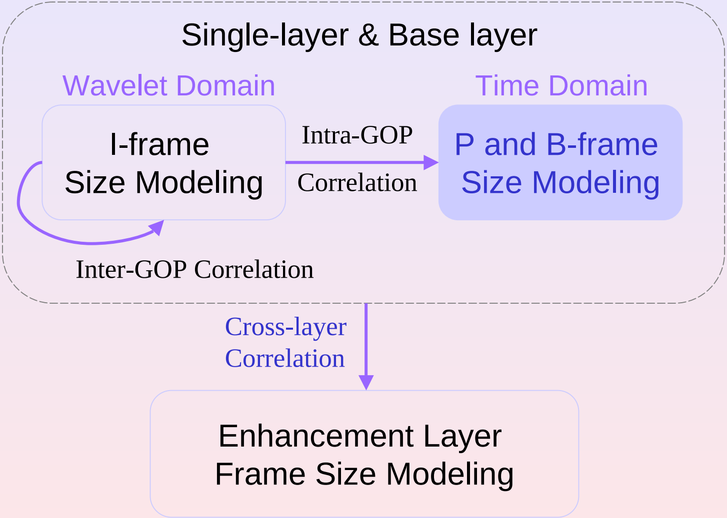


Figure: The ACF of the actual I-frame sizes and that of the synthetic traffic in (a) long range and (b) short range.


Single-layer & Base layer
Wavelet Domain
Time Domain
I-frame
Size Modeling
Intra-GOP
Correlation
P and B-frame
Size Modeling
Inter-GOP Correlation
Cross-layer
Correlation
Enhancement Layer
Frame Size Modeling

Modeling P/B-Frame Sizes

Intra-GOP Correlation

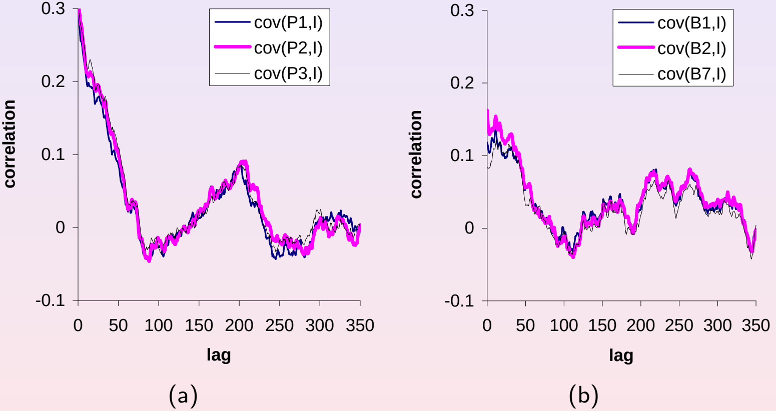


Figure: (a) The correlation between $\{\phi^I(n)\}$ and $\{\phi_i^P(n)\}$, $i = 1, 2, 3$, and (b) that between $\{\phi^I(n)\}$ and $\{\phi_i^B(n)\}$, $i = 1, 2, 7$ in Star Wars.

Modeling P/B-Frame Sizes

Model Comparison

Previous Work

Previous work does not consider the intra-GOP correlation and estimates P/B-frame sizes as i.i.d. random variables.

Our Model

The size of the i-th P-frame in the n-th GOP is:

$$\phi_i^P(n) = a\tilde{\phi}^I(n) + \tilde{v}(n), \quad \text{where} \quad a = \frac{r(0)\sigma_P}{\sigma_I}.$$

- Process $\tilde{\phi}^I(n) = \phi^I(n) - E[\phi^I(n)]$ and process $\tilde{v}(n)$ is independent of $\tilde{\phi}^I(n)$.
- Parameter σ_P is the standard deviation of $\{\phi_i^P(n)\}$, σ_I is the standard deviation of $\{\phi^I(n)\}$.

Modeling P/B-Frame Sizes

Performance Comparison

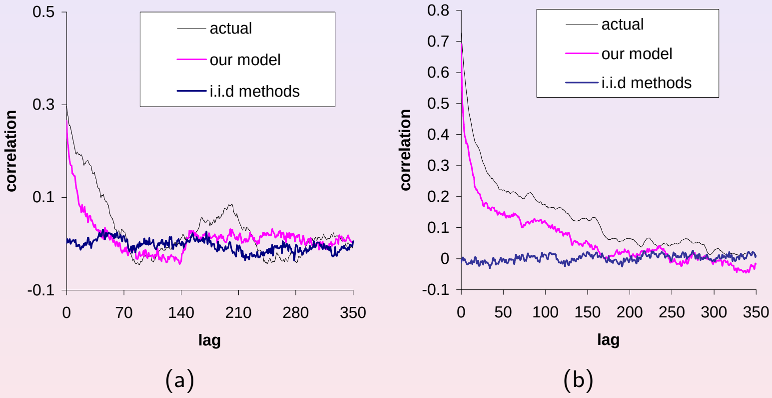


Figure: (a) The correlation between $\{\phi_1^P(n)\}$ and $\{\phi^I(n)\}$ in `Star Wars` and (b) that between $\{\phi_1^B(n)\}$ and $\{\phi^I(n)\}$ in `Jurassic Park`.

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Brief Description

Layered Video Coding

- Generates one base layer (BL) and one or more enhancement layers(EL)
- BL provides a low but guaranteed level of quality and EL provides quality improvement
- The input to an EL is the residual between the original image and the reconstructed image from the BL.

Cross-Layer Correlation

The enhancement layer has a strong dependency on the base layer, which is referred to as cross-layer correlation.

Brief Description (cont.)

Definition

Assuming that $n \geq 1$ represents the GOP number in an enhancement layer,

1. $\varepsilon^I(n)$ is the I-frame size in this GOP.
2. $\varepsilon_i^P(n)$ is the size of the i-th P-frame in this GOP.
3. $\varepsilon_i^B(n)$ is the size of the i-th B-frame in this GOP.

Modeling Enhancement Layer

Algorithm

1. We estimate I-frame sizes in wavelet domain
2. Estimate P and B-frame sizes using the cross-layer correlation:

$$\varepsilon_i^P(n) = a\phi_i^P(n) + \tilde{w}_1(n),$$
$$\varepsilon_i^B(n) = a\phi_i^B(n) + \tilde{w}_2(n),$$

where $a = r(0)\sigma_\varepsilon/\sigma_\phi$.

- Parameter $r(0)$ is the lag-0 cross-correlation coefficient, σ_ε and σ_ϕ are the standard deviation of the EL and the corresponding BL.
- Processes $\{\tilde{w}_1(n)\}, \{\tilde{w}_2(n)\}$ are independent of $\{\phi_i^P(n)\}$ and $\{\phi_i^B(n)\}$.

Modeling Enhancement Layer

Cross-correlation Comparison

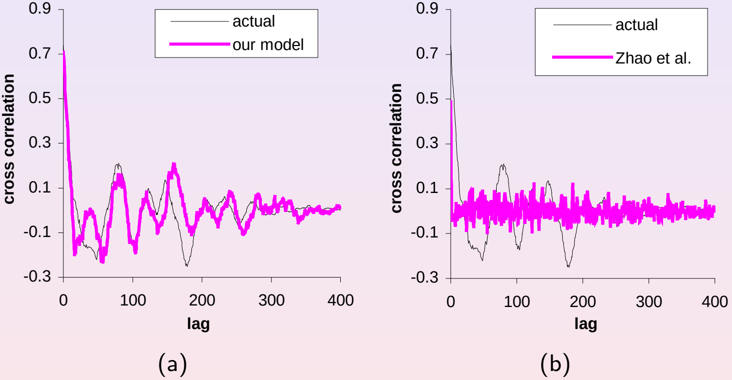

Figure: The cross-correlation between $\{\varepsilon^I(n)\}$ and $\{\phi^I(n)\}$ in The Silence of the Lambs and that in the synthetic traffic generated from (a) our model and (b) a popular model in related work.

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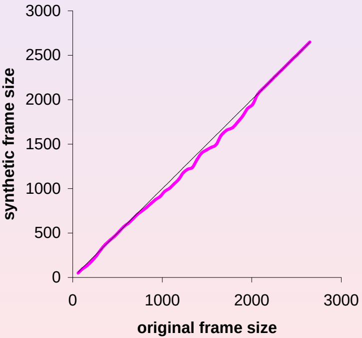
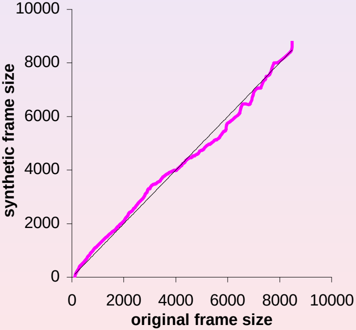
Performance Evaluation Methods

QQ Plots

- To verify the distribution similarity between the original traffic and the synthetic one.



(a) Base-layer

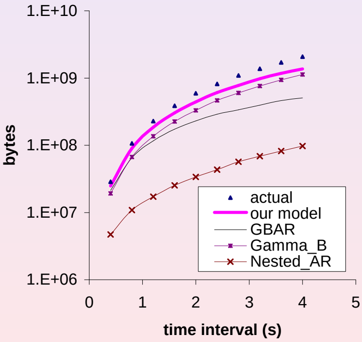


(b) Enhancement layer

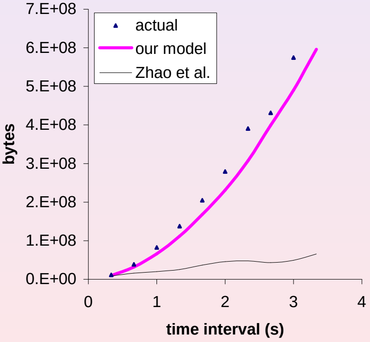
Performance Evaluation Methods (cont.)

Variance of traffic during various time intervals

- To check whether the second-order moment of the synthetic traffic fits that of the original one.



(a) Star Wars BL



(b) Star Wars EL

Performance Evaluation Methods (cont.)

Leaky-bucket simulation

- To examine how well the traffic model preserves the temporal information of the original traffic
- Implementation: Pass the original and synthetic traffic through a generic buffer with capacity c and drain rate d.
- Evaluation metric:

$$e = \frac{|p - p_{model}|}{p},$$

where p is the actual data loss ratio and p_{model} is the synthetic one.

Performance Evaluation Methods (cont.)

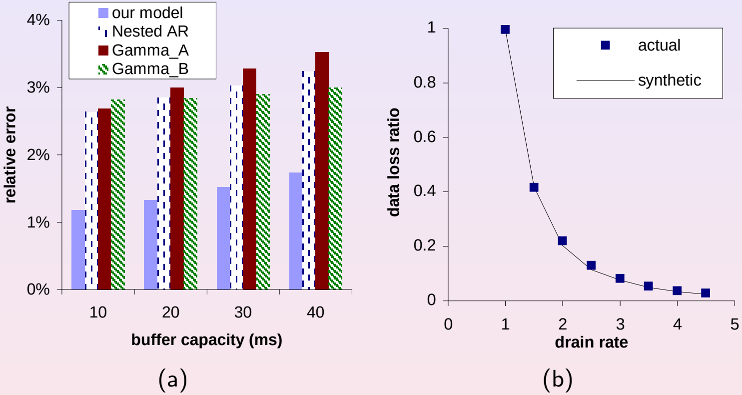


Figure: (a) Comparison of several models in H.264 coded `Starship Troopers`. (b) The loss ratio p of the original and synthetic enhancement layer traffic for `The Silence of the Lambs`.

Conclusion

- This paper proposed a traffic model applicable to both single-layer and multi-layer VBR video traffic.
- The presented traffic modeling framework captures both LRD and SRD properties of video traffic.
- This framework accurately describes both inter-/intra-GOP correlation and the cross-layer correlation.

- Future Work
  - Develop a unified model for multi-layer video traffic
  - More applications in overlay networks

Thank you!

Any questions?