Wavelet and Time-Domain Modeling of Multi-Layer VBR Video Traffic

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Agenda

- Background
  - Importance of traffic modeling
  - Goals of traffic modeling
  - Preliminary knowledge of video traffic
- Challenges & Current Status
- Our Work
  - Modeling single-layer video traffic
  - Modeling multi-layer video traffic
- Conclusion

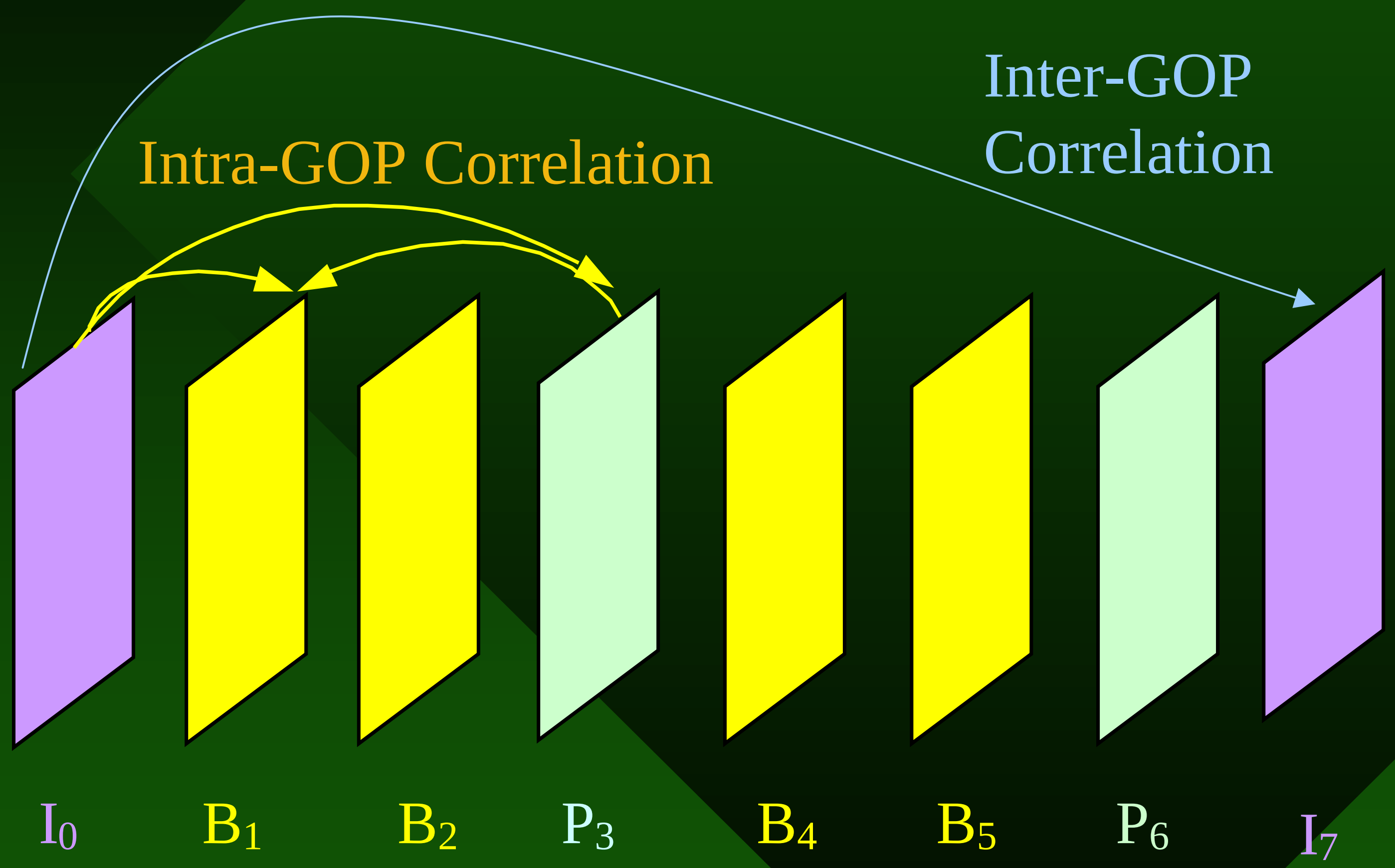
Importance of Traffic Modeling

- 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

- 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

Preliminary



Group of Pictures (GOP)

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Challenges

- The PDF is different among I, P, and B-frame sizes
- VBR video traffic exhibits both long range dependency (LRD) and short range dependency (SRD).
- Single-layer and base layer video traffic:
  - Coexistence of inter- and intra-GOP correlation
- Multi-layer video traffic:
  - Strong cross-layer correlation

Current Status

- It is hard to capture both LRD and SRD properties of the autocorrelation function of video traffic
- Little work has considered the intra-GOP correlation
- Most existing models only apply to single-layer VBR video traffic
- Current multi-layer traffic models do not capture the cross-layer correlation

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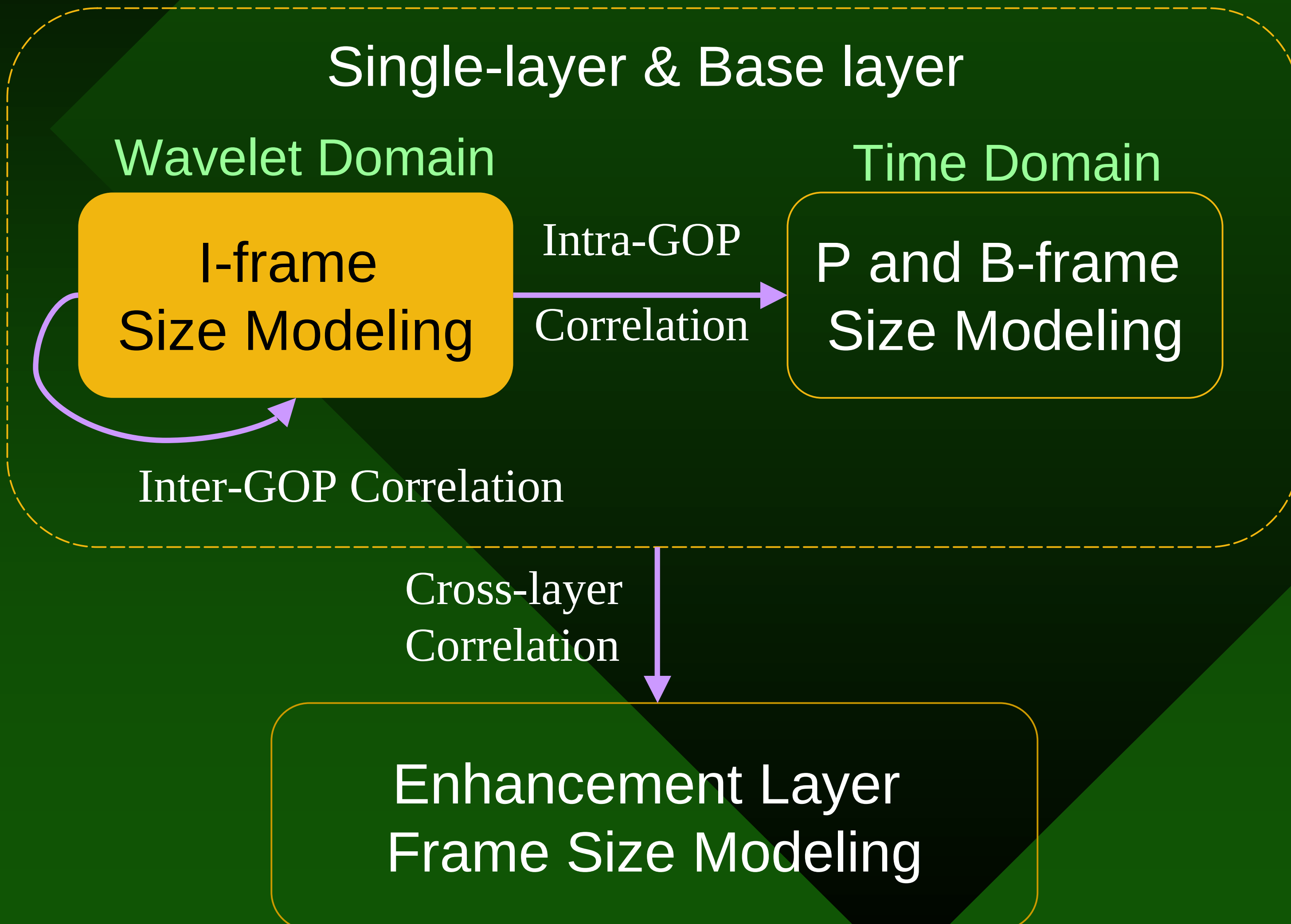
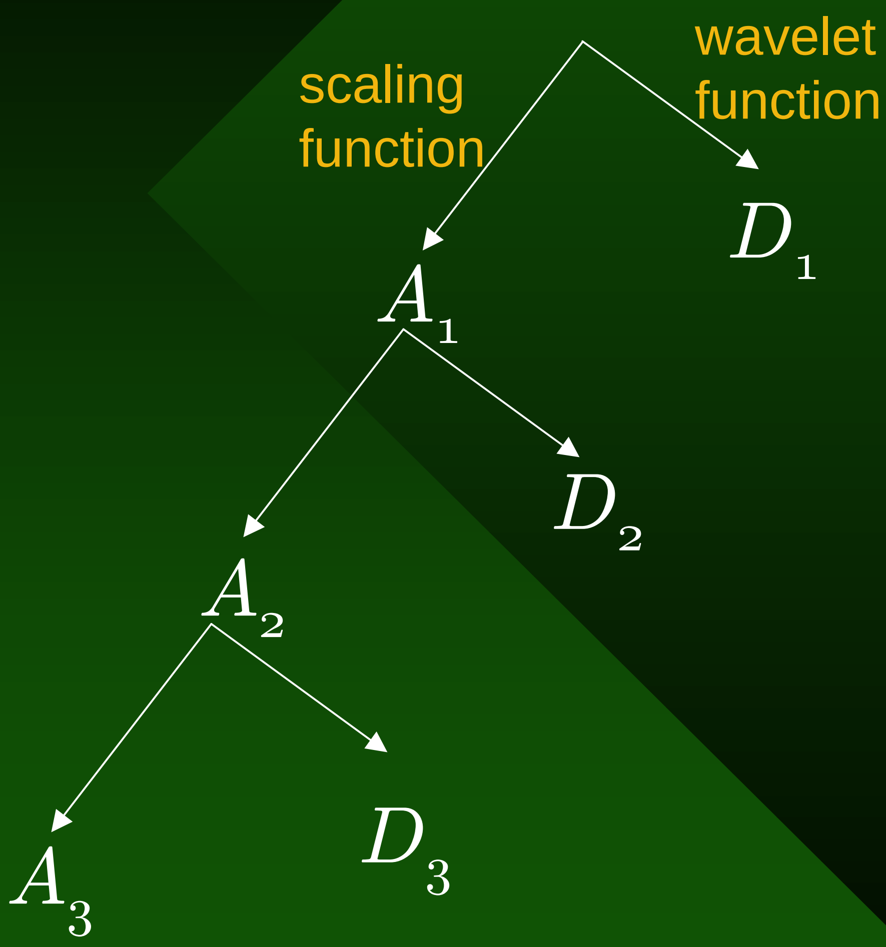
Our Work



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

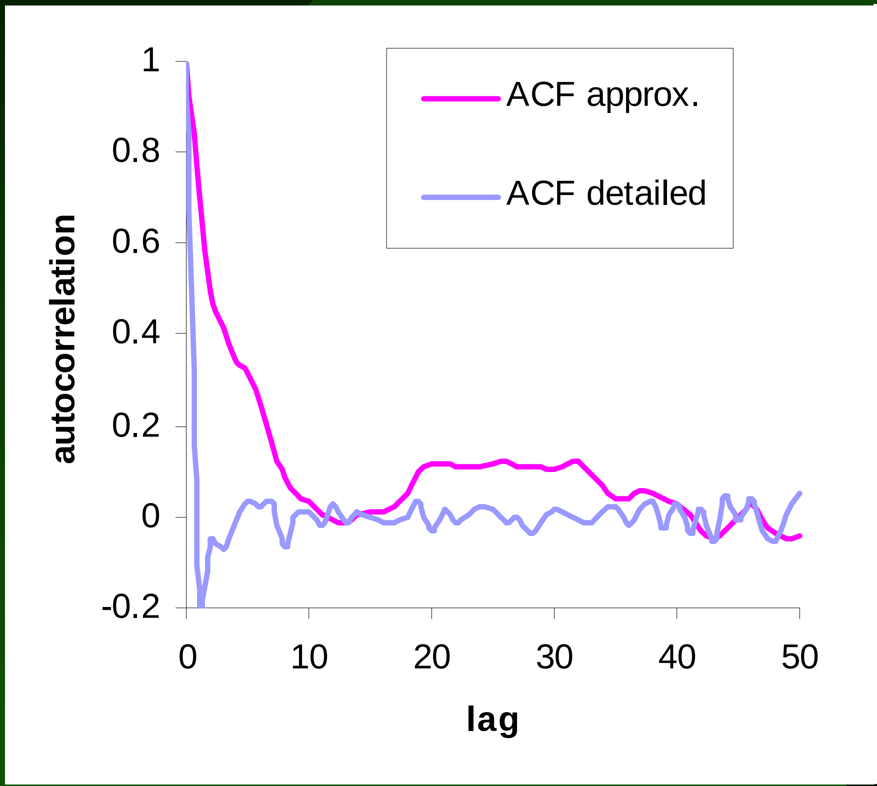
Wavelet Decomposition

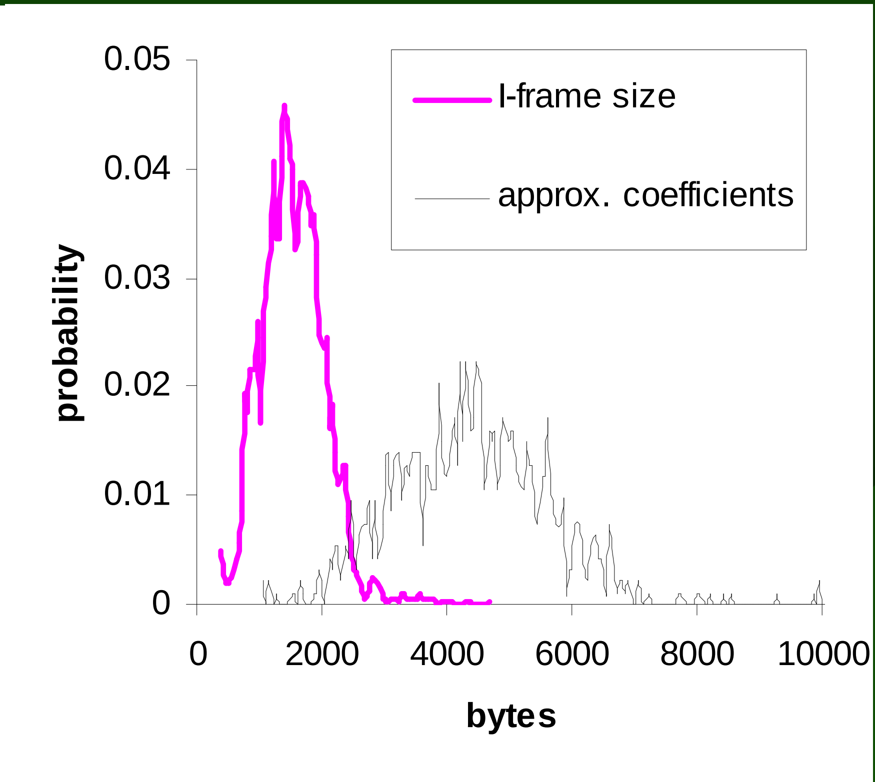


- Wavelet function generates the detailed coefficients $\{D_j\}$ and scaling function generates the approximation coefficients $\{A_j\}$, where j is the decomposition level.

A typical wavelet decomposition.

Wavelet Decomposition (cont.)



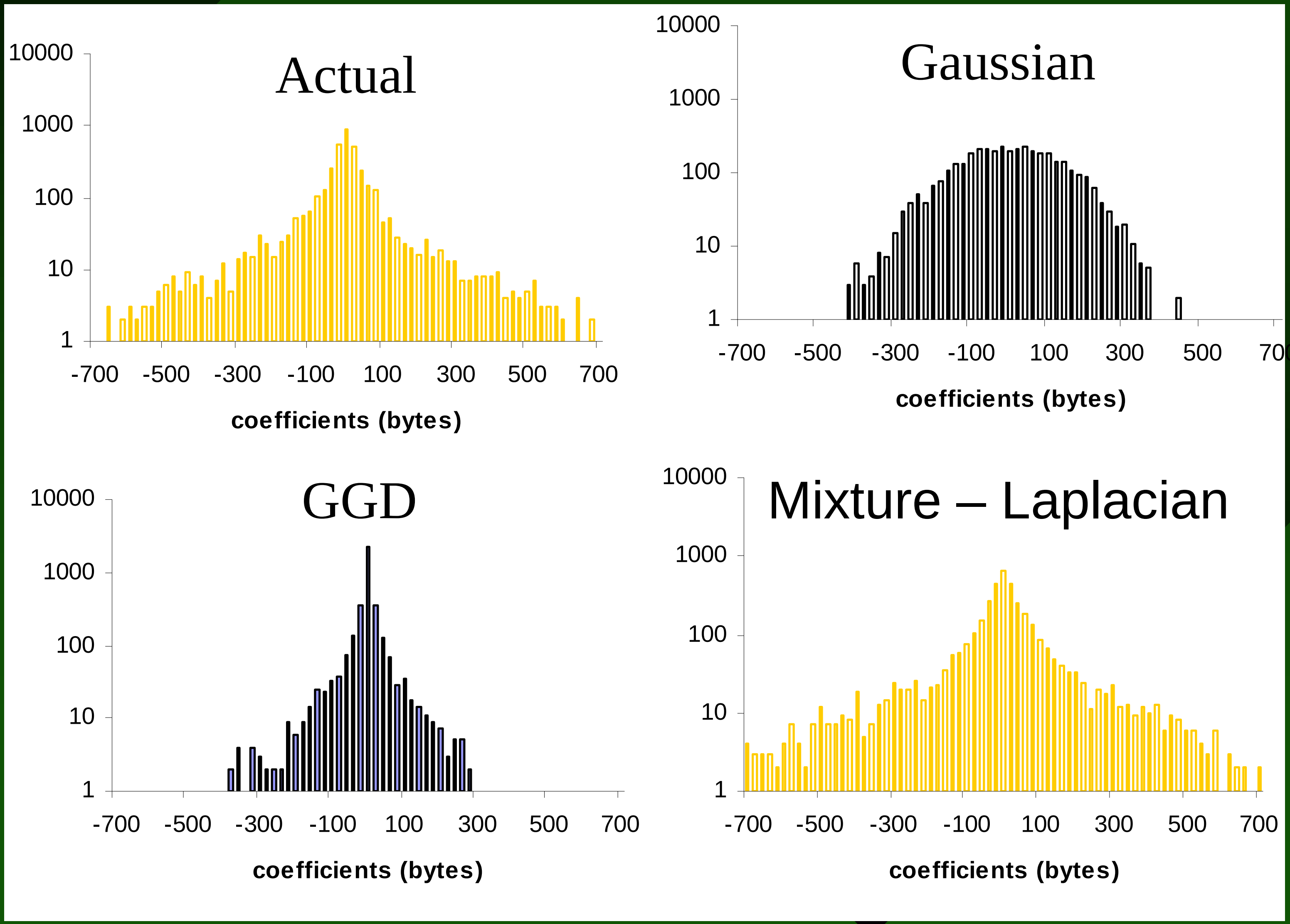


The ACF structures of $\{D_3\}$ and $\{A_3\}$ (left). The PDF of I-frame sizes and that of $\{A_3\}$ (right).

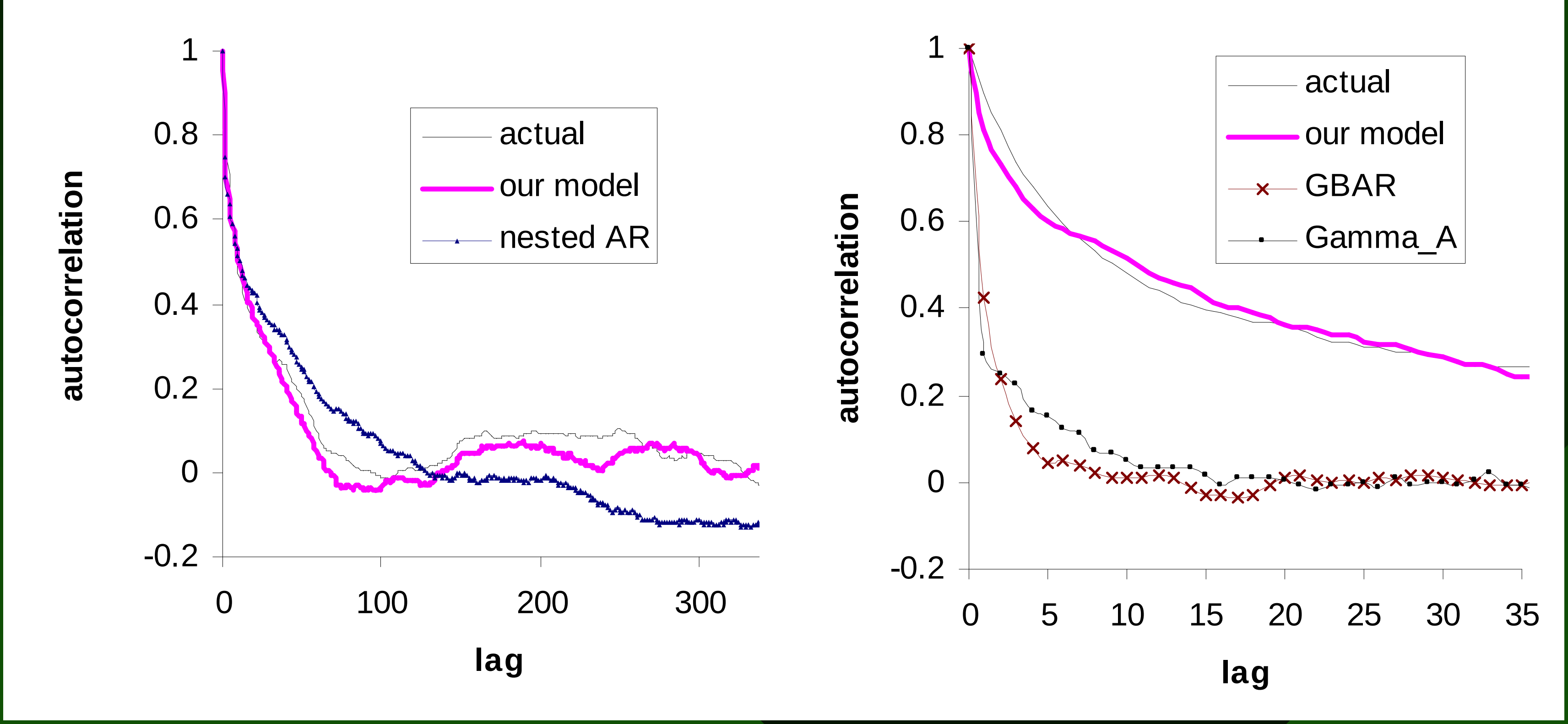
Modeling I-Frame Sizes

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

Estimate Detailed Coefficients

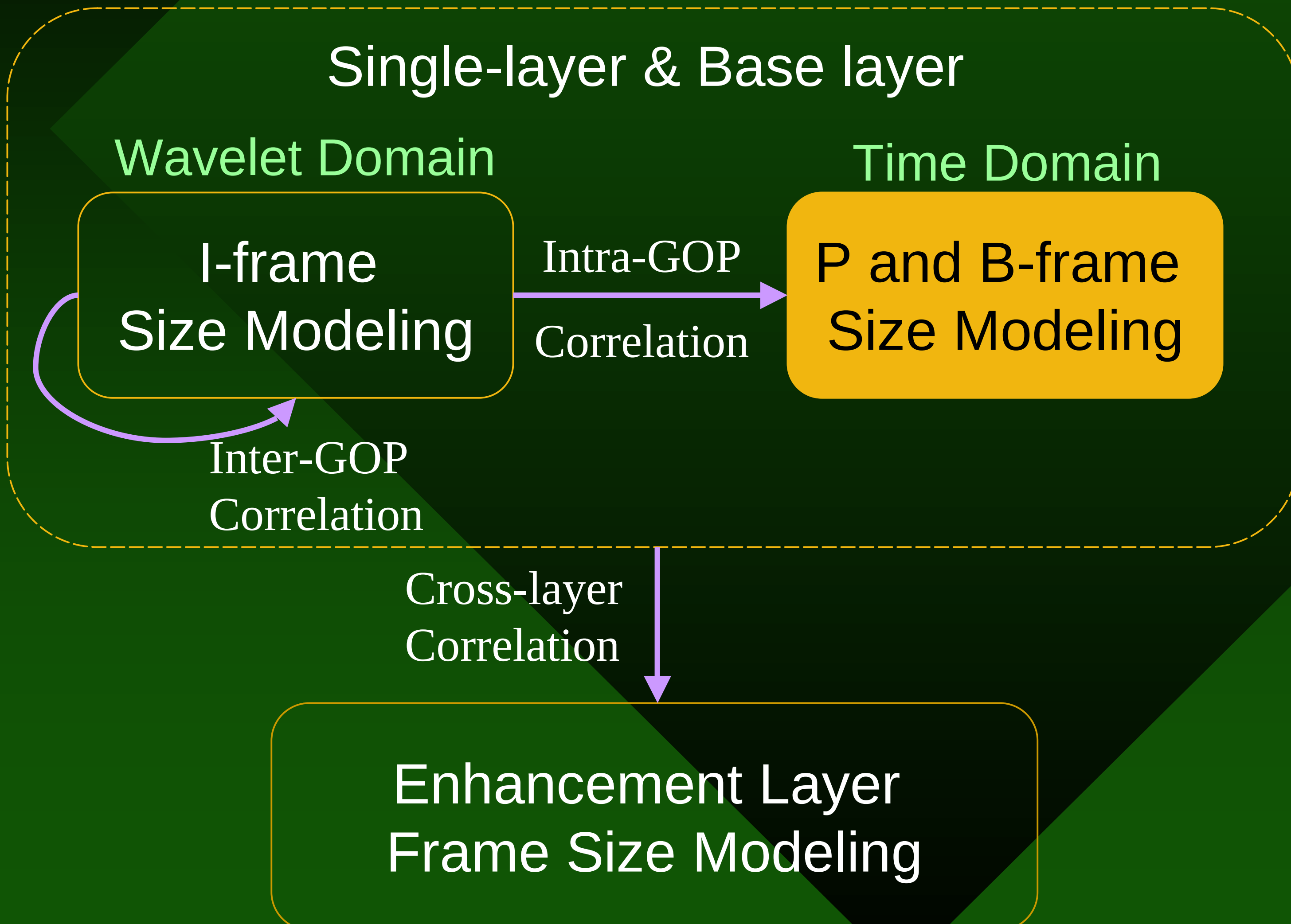


Performance Comparison



The ACF structure of the actual and that of the synthetic traffic in a long range (left) and short range (right).

Our Work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Modeling P/B-Frame Sizes

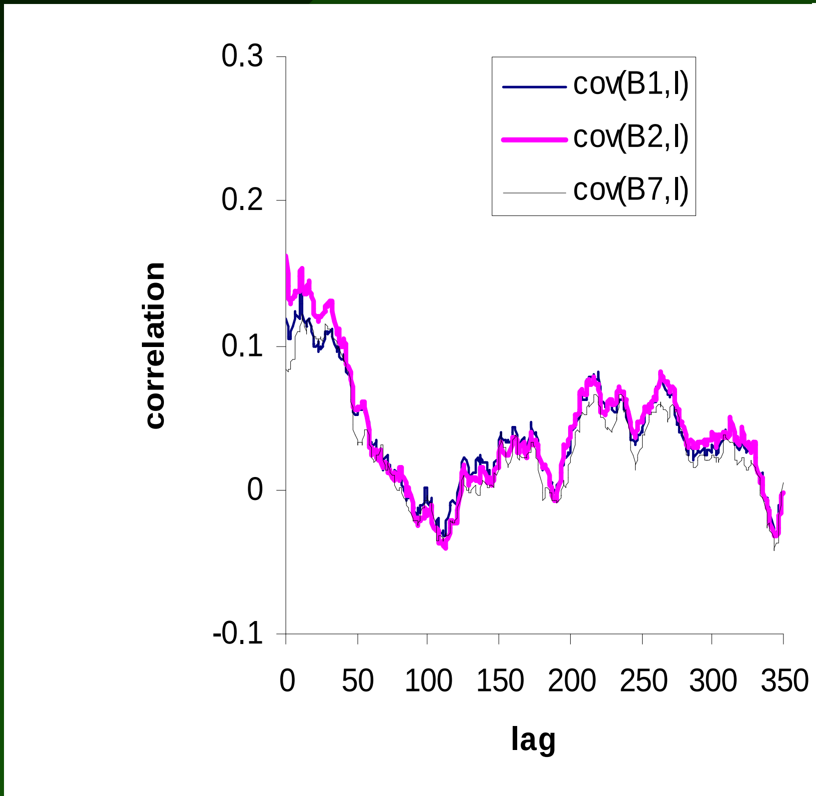
- Assume that GOP structure is fixed, e.g., *IBBPBBPBBPBB*
- Definition: In the n-th GOP,
  - $\phi^I(n)$ — the I-frame size
  - $\phi_i^P(n)$ — the size of the i-th P-frame
  - $\phi_i^B(n)$ — the size of the i-th B-frame
- For example, $\phi_3^P(10)$ represents the size of the third P-frame in the 10-th GOP

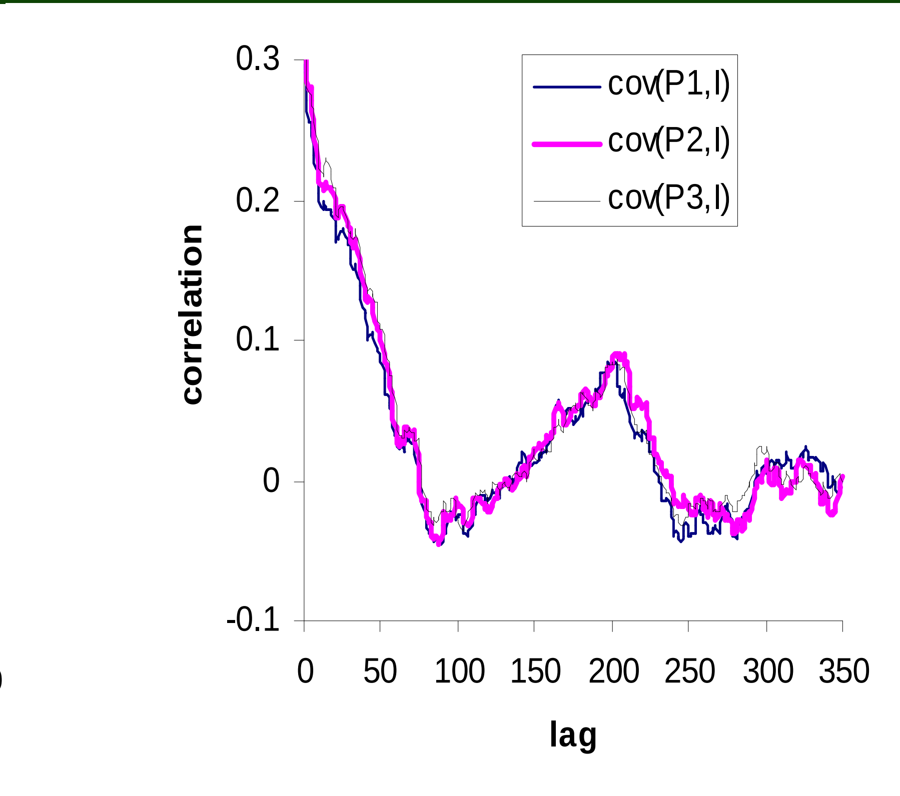
Intra-GOP Correlation

- Most previous work does not consider intra-GOP correlation and estimates P and B-frame sizes as *i.i.d*. random variables

- However, intra-GOP correlation is important and has similar structures between $\phi_i^P(n)$ and $\phi^I(n)$, with respect to different i.

Intra-GOP Correlation (cont.)





The correlation between different B-frame sequences and the I-frame sequence (left). That between different P-frame sequences and the I-frame sequence (right).

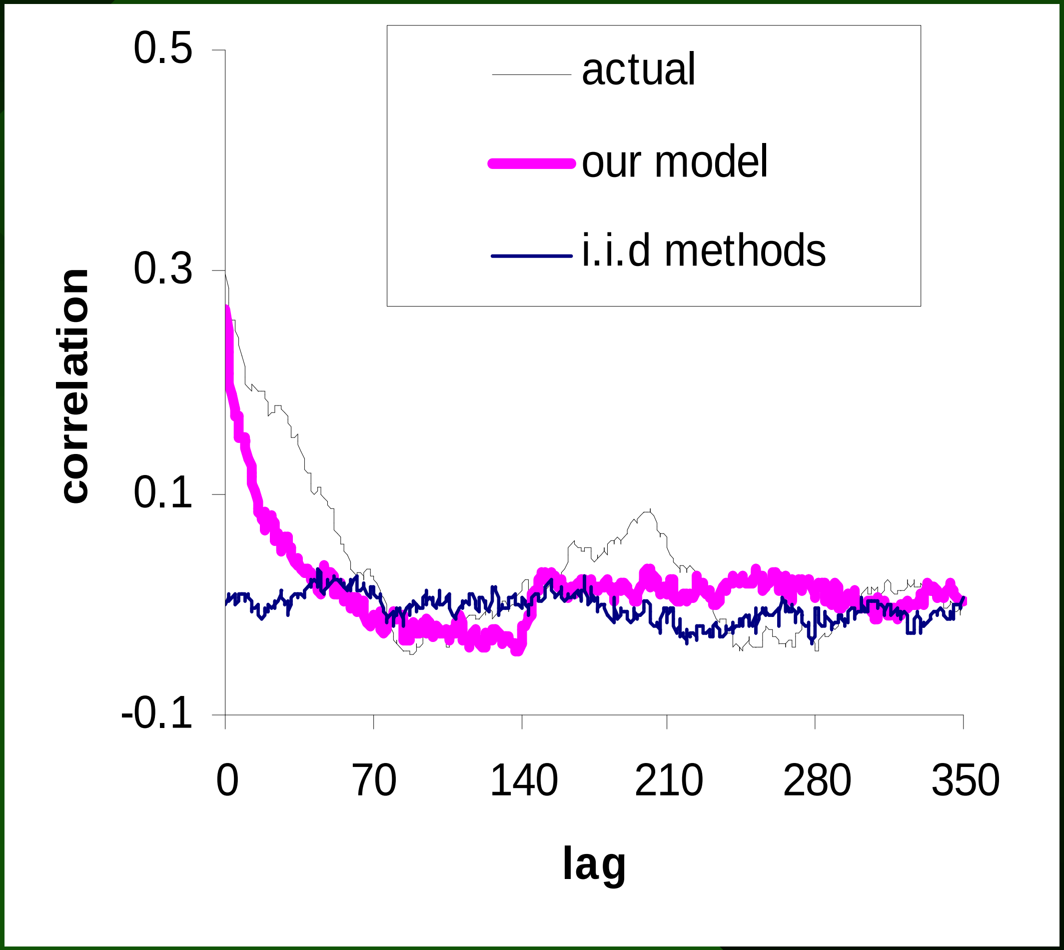
Modeling P-Frame Sizes

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

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

  - Process $\tilde{\phi}^I(n) = \phi^I(n) - E[\phi^I(n)]$, and $\tilde{v}(n)$ is independent of $\tilde{\phi}^I(n)$.
  - Parameters σ_P and σ_I are the standard deviation of $\{\phi_i^P(n)\}$ and $\{\phi^I(n)\}$, respectively.
  - Parameter $r(0)$ is the lag-0 correlation coefficient.

Performance Comparison



The correlation between $\phi_1^P(n)$ and $\phi^I(n)$ in Star Wars.

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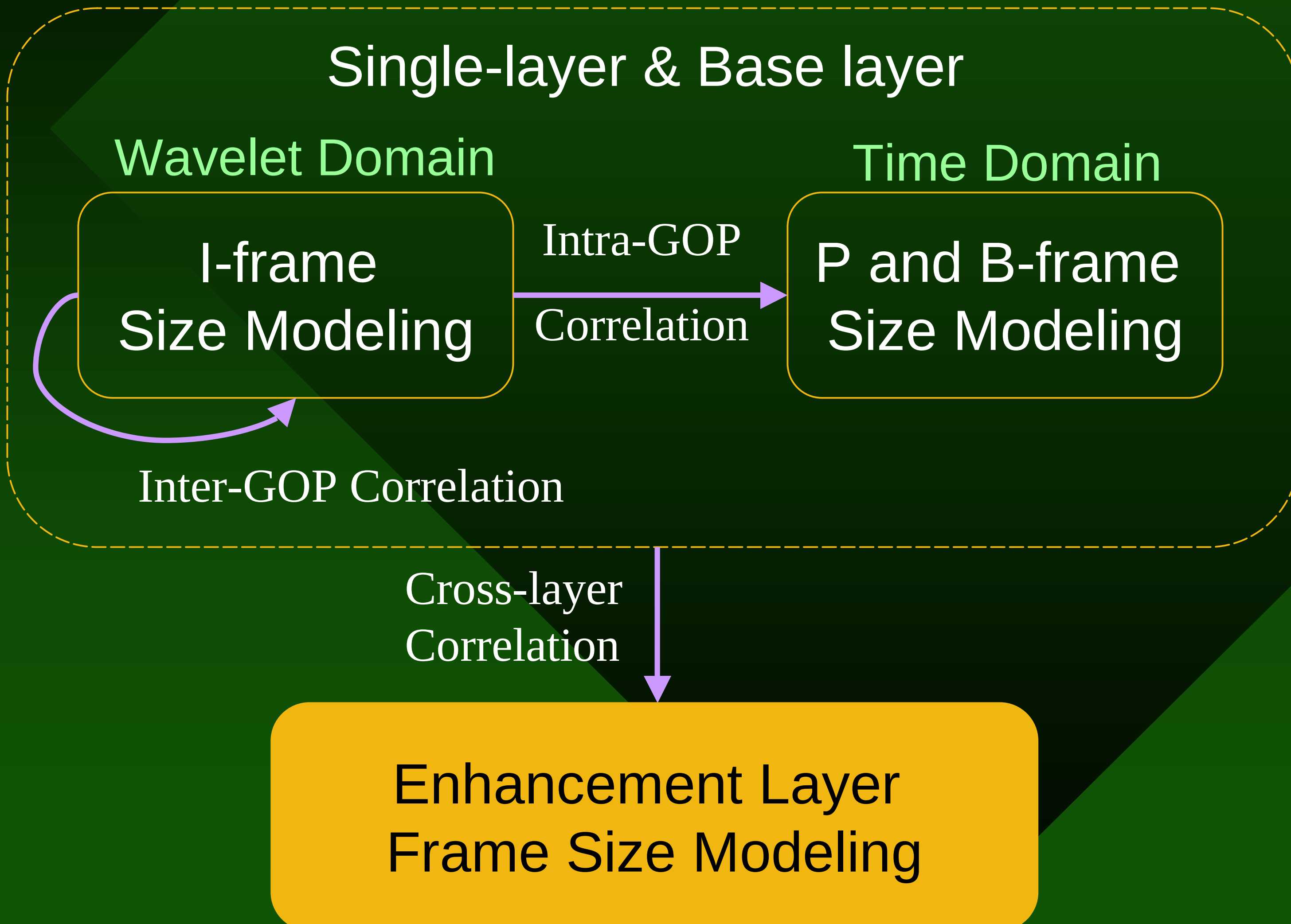
Our Work



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Modeling Enhancement Layer

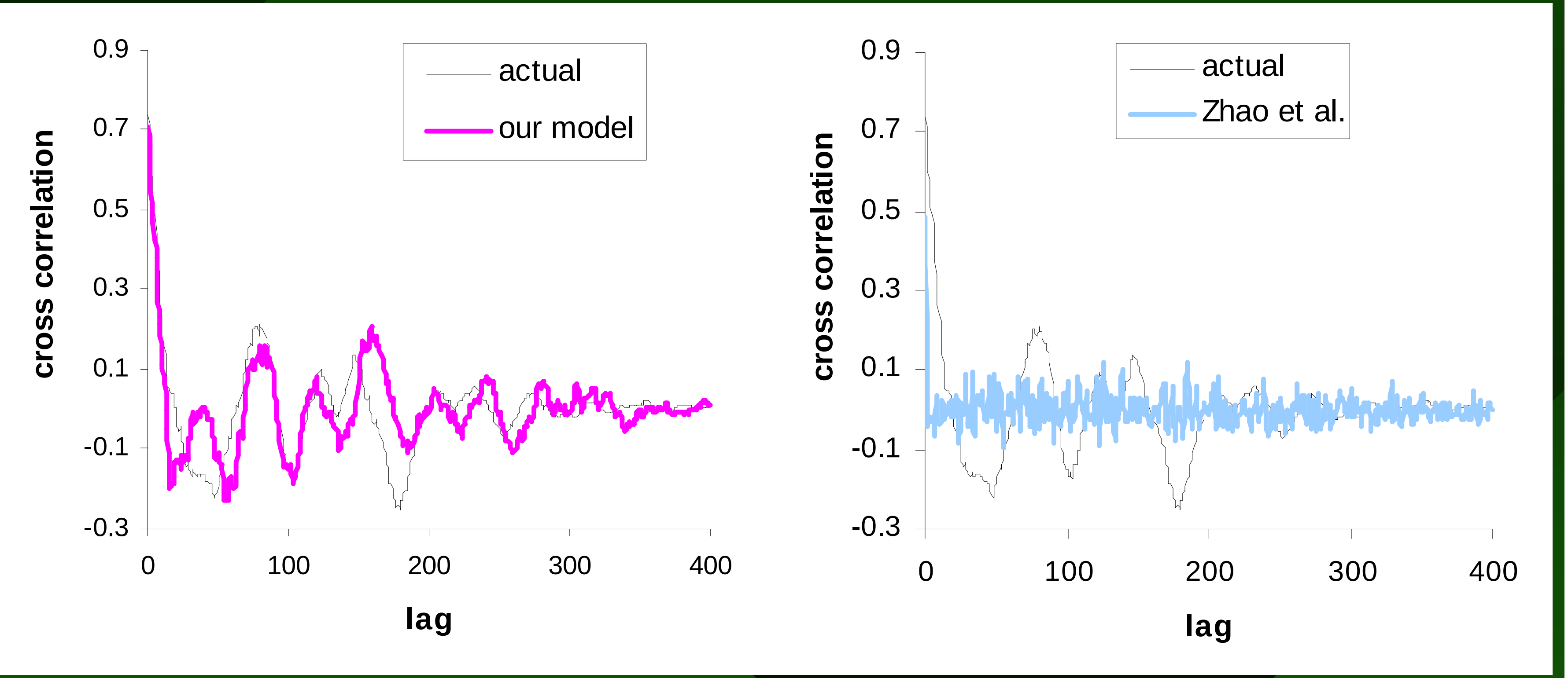
- We estimate I-frame sizes in wavelet domain
- We estimate P and B-frame sizes using the cross-layer correlation:

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

where $a = r(0)\frac{\sigma_\varepsilon}{\sigma_\phi}$.

  - where $\varepsilon_i^P(n)$ is the size of the *i*-th P-frame, and $\varepsilon_i^B(n)$ is the size of the *i*-th B-frame
  - Parameter $r(0)$ is the lag-0 cross correlation coefficient, σ_ε and σ_ϕ are the standard deviation of the enhancement layer sequence and its corresponding base layer sequence.

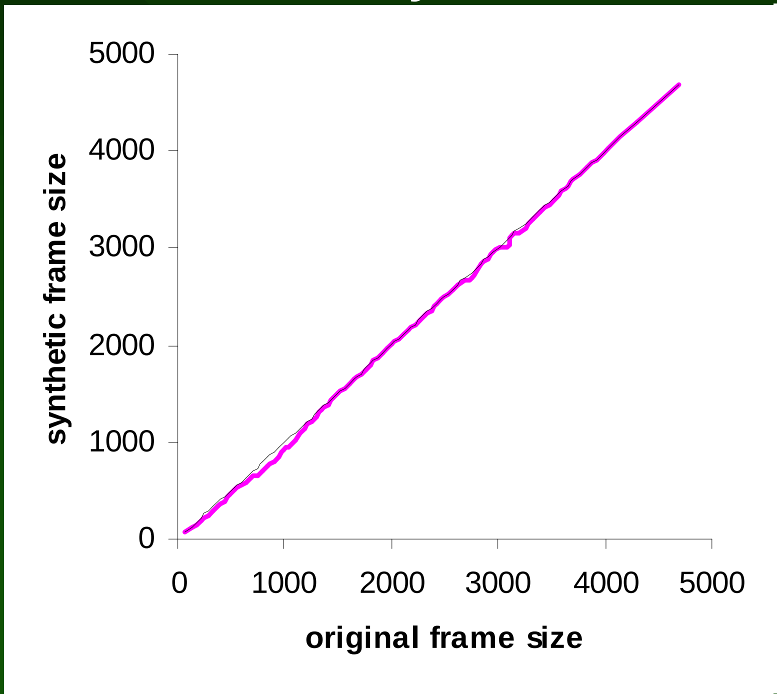
Performance

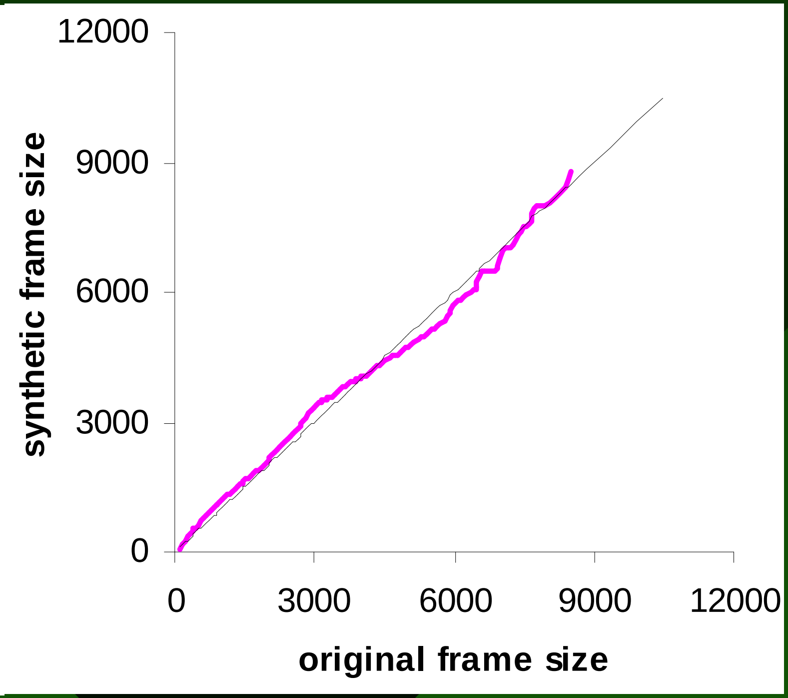


The cross correlation in the original and synthetic *The silence of the Lambs*.

Model Accuracy Study

- QQ plots
  — Verify the distribution similarity between the original traffic and the synthetic one





QQ plots for the synthetic single-layer *Star Wars* (left) and the synthetic enhancement layer *The Silence of the Lambs* (right).

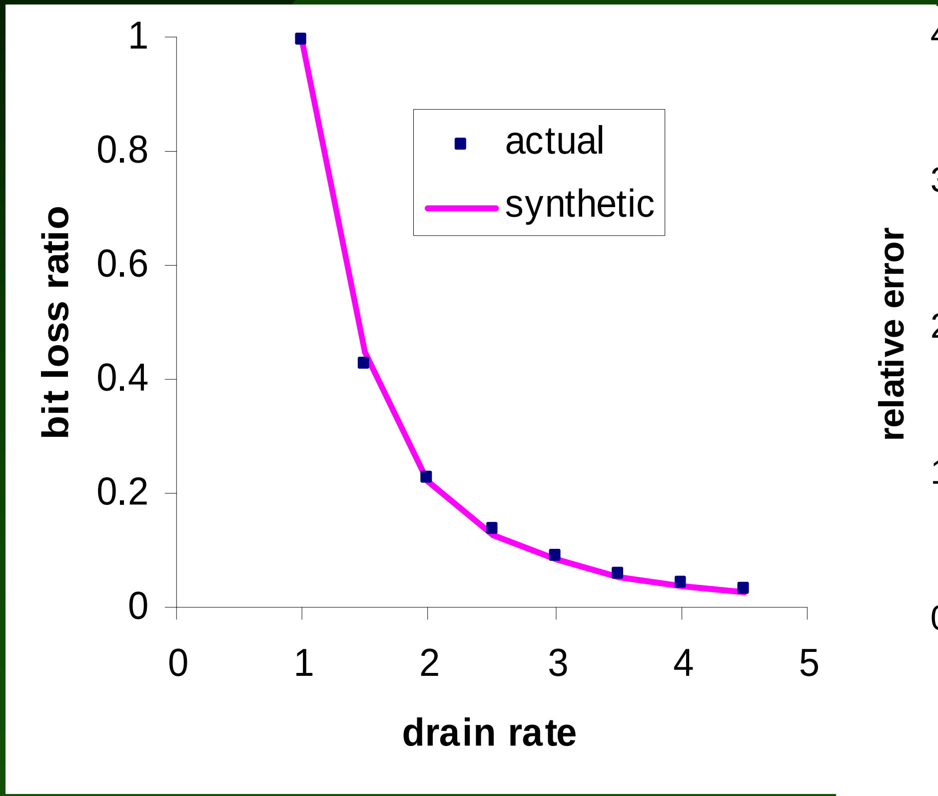
Model Accuracy Study (cont.)

- Leaky-bucket simulation
  - 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:

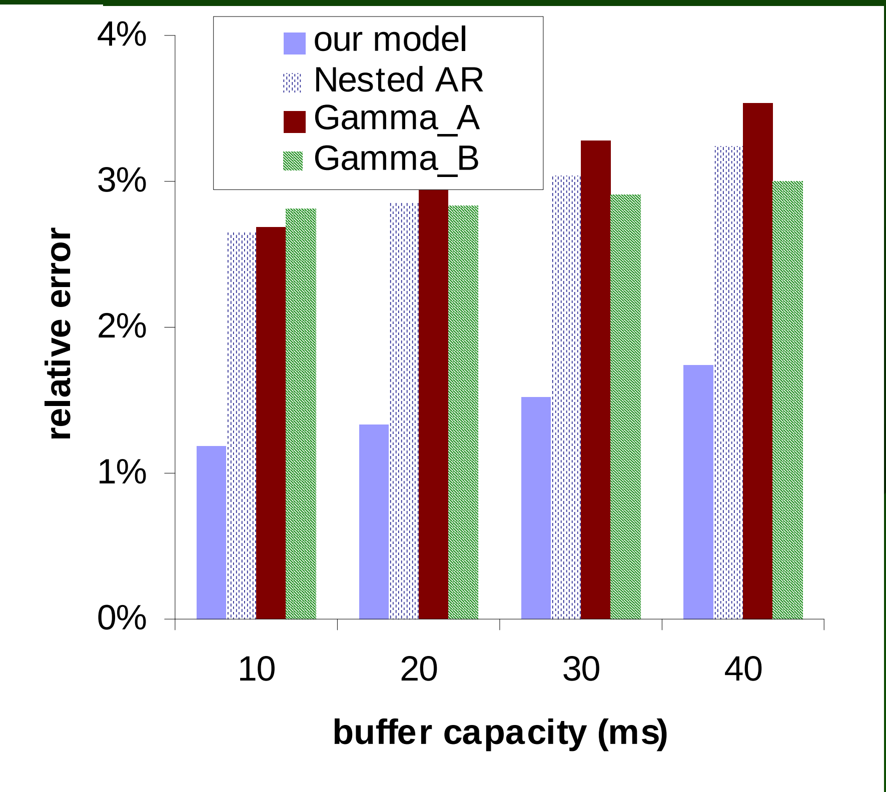
$$e = \frac{|p - p_{model}|}{p}$$

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

Model Accuracy Study (cont.)



The loss ratio p of the original and synthetic *The Silence of the Lambs* enhancement layer



Comparison of several models in H.26L coded *Starship Troopers*

Conclusion

- This paper proposes 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 the intra-GOP correlation and the cross-layer correlation.