Bridge the Gap Between QoS and QoE in Mobile Short Video Service: a CDN Perspective

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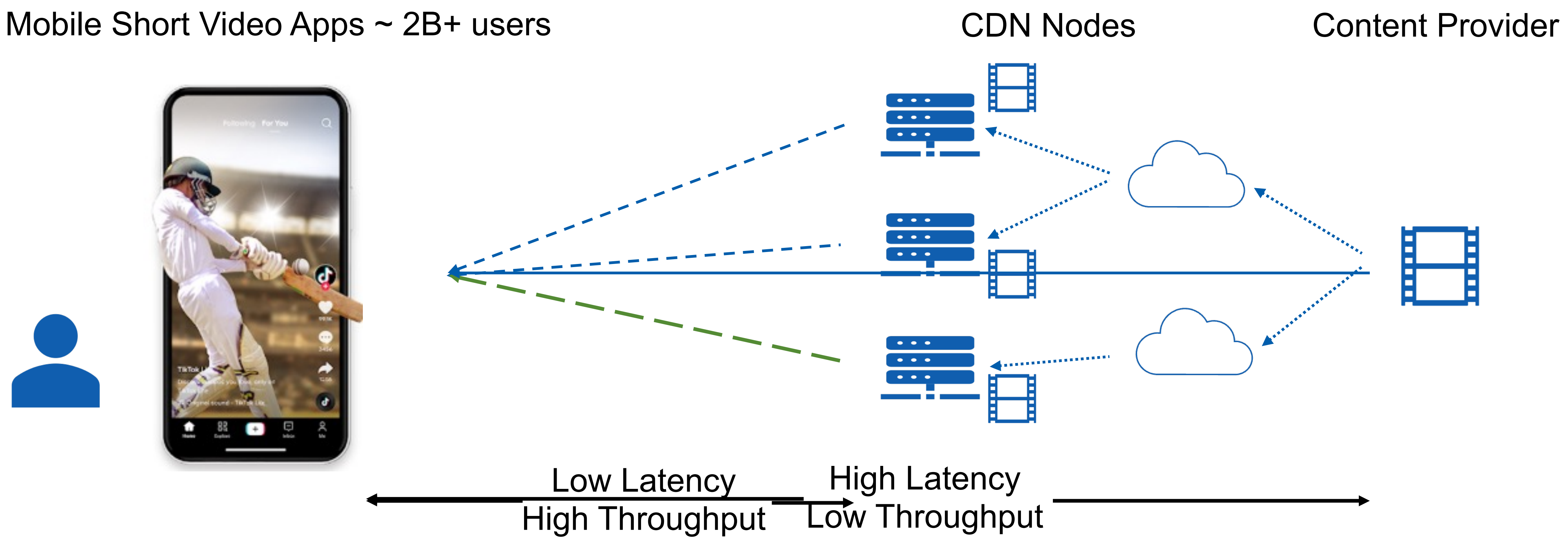
Background: Content Delivery Network (CDN)

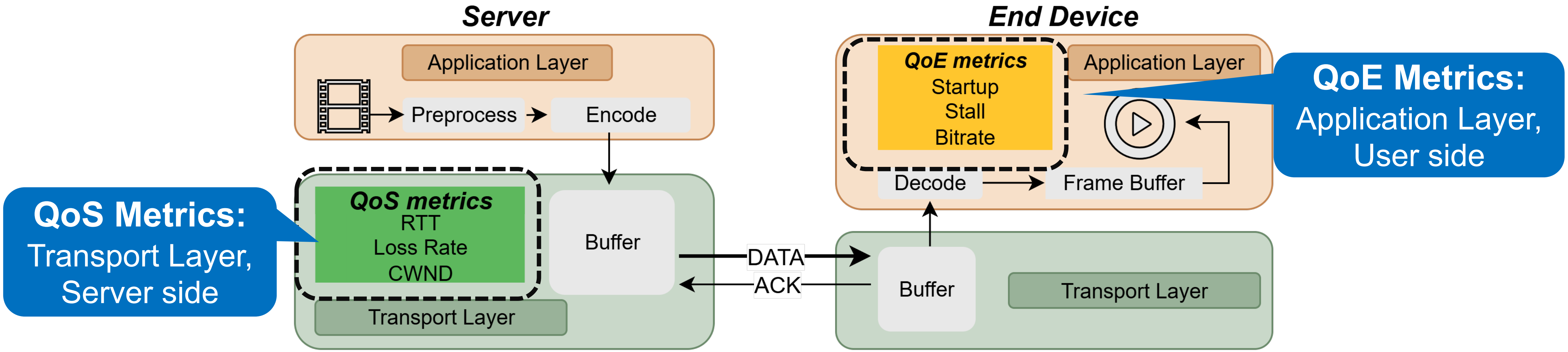
- CDNs support emerging mobile short video services.



CDN's goal is to optimize **performance** for serving applications by **scheduling**.

Performance Metrics: QoE ≠ QoS

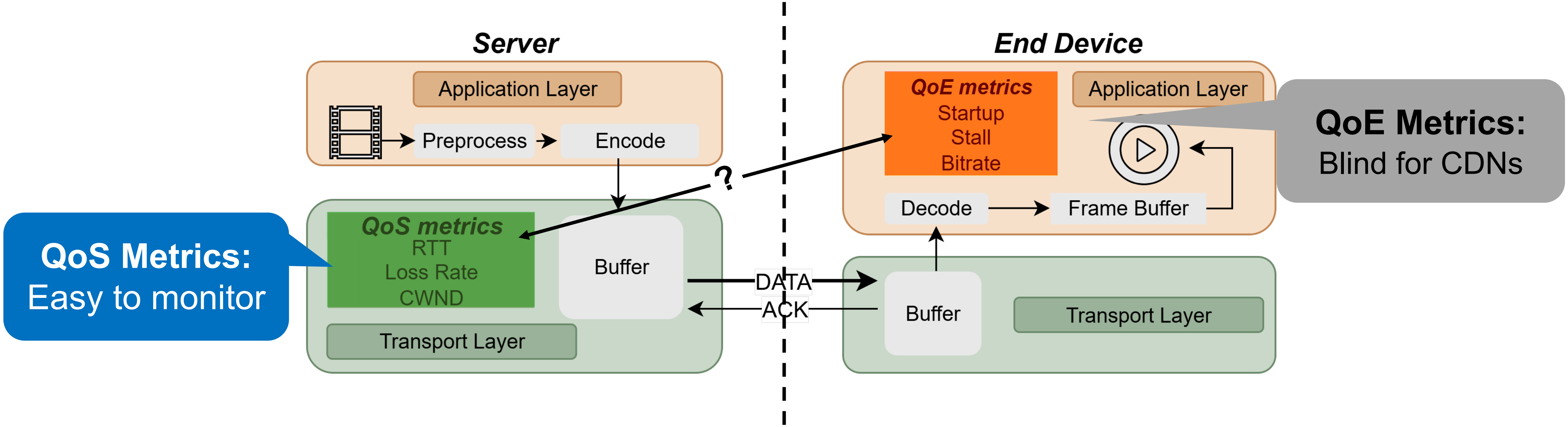
- Users care **Quality of Experience** (QoE)
  - Startup delay, stall, bitrate selection, etc. in playback
- CDNs monitor **Quality of Service** (QoS)
  - RTT, loss rate, throughput, etc. in network stack



Core Problem: QoS and QoE are mismatched.

Motivation: Bridge the QoS-QoE Gap

- CDN cannot observe QoE directly.
- CDN's efforts to improve QoE cannot always take effects.
  - $QoS \uparrow \nRightarrow \mathrm{QoE} \uparrow$



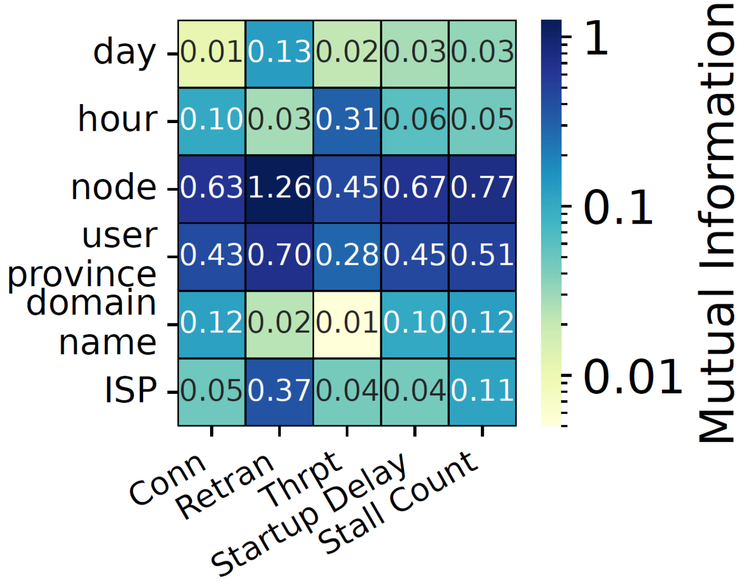
Goal: Construct QoS-QoE mappings for **scheduling** to achieve better QoE

Complex QoS-QoE Relationship

- Q: Can we simply use a **supervised model** to predict QoE from QoS?
- A: Data-driven prediction model requires complex scenario features as input.
  - Scenario features have strong correlation with QoE.

Features	Startup Delay / %	Stall Count / %
QoS	6.0	23.7
QoS + Scenarios	3.1 1.9×	8.7 2.7×

XGBoost model's prediction accuracy with different input features.



Mutual Information between metrics and scenario features.

Design challenge: Complex scenario features reduce interpretability.

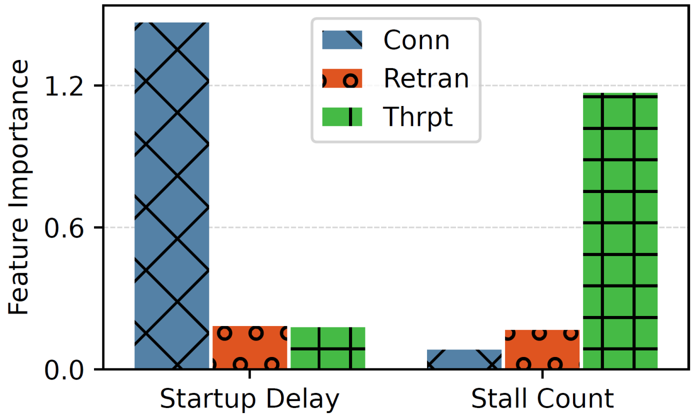
Core Idea: From modeling to clustering

PATTERN	GROUP	APPLY
Visualize QoS-QoE mappings Use Quasi-Experimental Design (QED) to generate a large set of QoS-QoE mapping patterns.	**Cluster** to summarize scenarios Apply K-Medoids clustering to group patterns and extract representative "meta-scenarios".	**Schedule** with predicted QoE Build cluster-specific prediction models to power a new QoE-aware CDN scheduling objective.

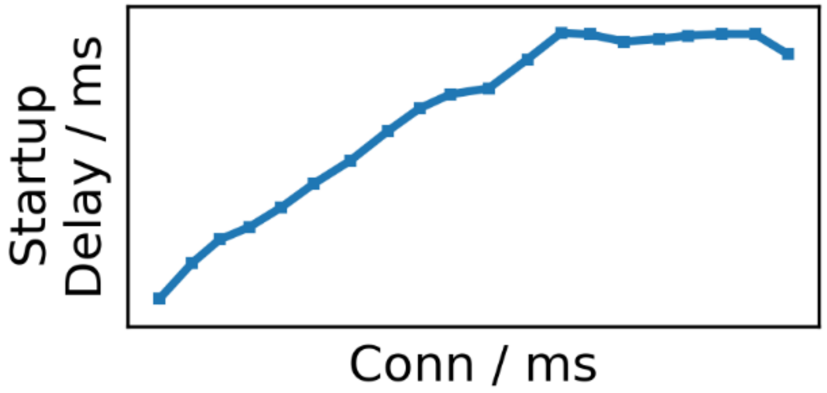
Step 1: Uncovering Individual Patterns via QED

- Observation: QoE metrics are strongly related to **one** corresponding QoS metrics.
- Quasi Experimental Design (QED): Construct univariate functions under different scenarios.

$$QoE_i = f(QoS_i | scenarios)$$



Feature importance for different QoE metrics.



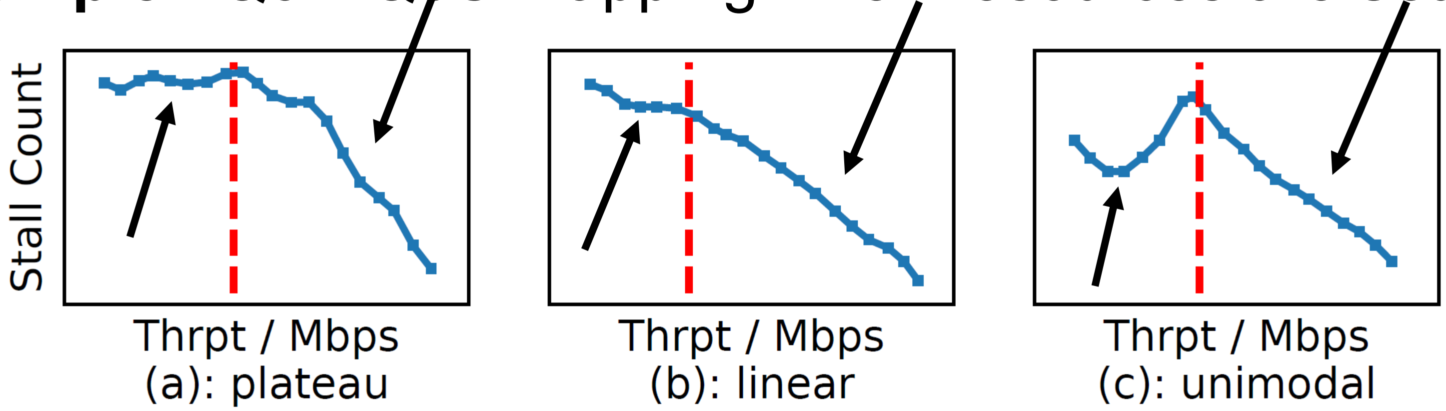
Example for the pattern of univariate function.

Key result: 1,800+ visualized patterns under corresponding scenarios.

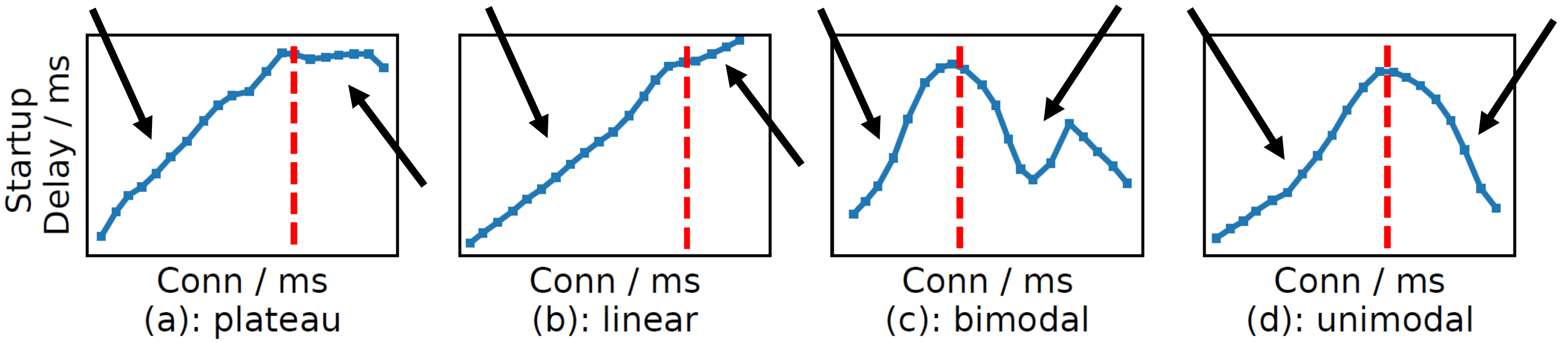
Step 2: Summarizing Scenarios with Clustering

- K-Medoids **clustering** with Dynamic Time Warping (DTW) distance.
- **Observation**:
    1. Approximately **linear** QoE-QoS mapping when resources are **abundant**.
    2. **Non-linear and complex** QoE-QoS mapping when resources are **scarce**.

<throughput, stall count>



<connection setup time, video startup delay>



Implication for Scheduling

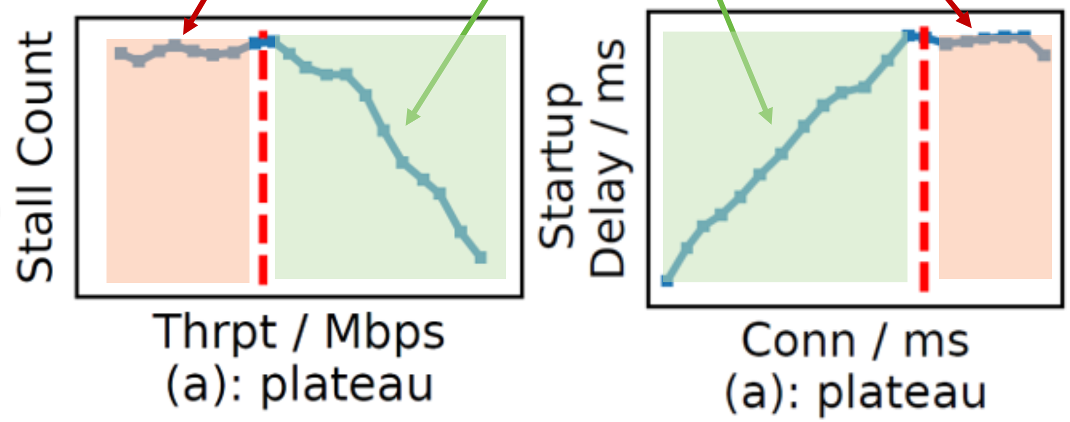
- Insight 1: **Performance** differentiated node utilization strategies.
  - Maximize utilizing efficiency for *high-performance nodes*.
- Insight 2: **Time** differentiated scheduling strategies.
  - Maximize QoE for *users*.

Low QoS, conservative strategies, less QoE loss

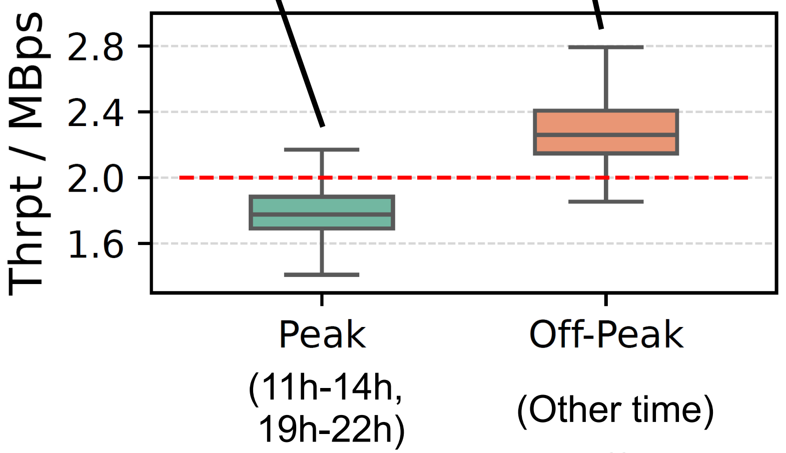
QoE Almost No Change → Poorer QoS is ok.

High QoS, aggressive strategies, better QoE gain.

QoS Improvement Zone → Better QoS helps.



Plateau shaped QoS-QoE mapping pattern.



Throughput distribution at different times.

Step 3: QoE-Aware CDN Scheduling

- CDN scheduling is an optimization problem to find the scheduling strategy X.

$$\min_X \boxed{D_{ij}} \cdot X_{ij}$$

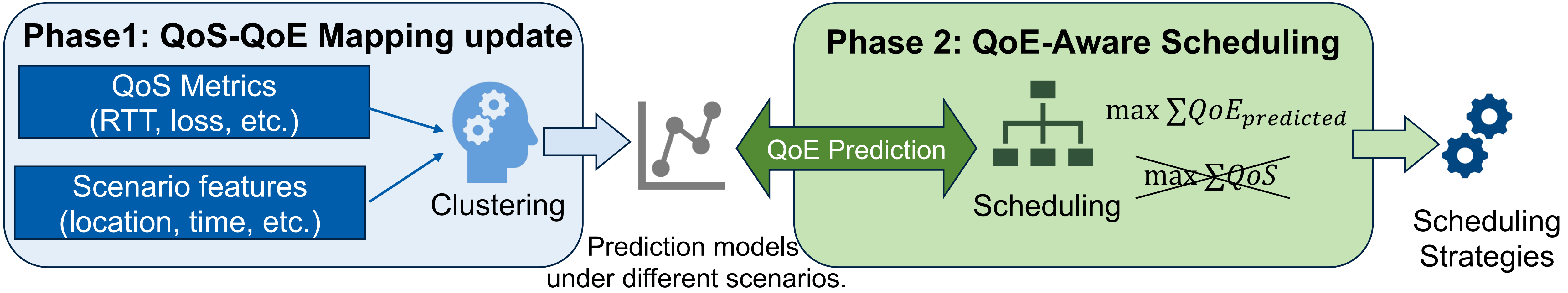
Cost function D_{ij} is predicted QoE, instead of QoS.

$$s.t. \sum_j X_{ij} \le C_i, \forall i \in N;$$

CDN node capacity constraints.

$$\sum_i X_{ij} = T_j, \forall j \in M.$$

Traffic allocation constraints.



Evaluation: Clustering-based Prediction

- Real-world collected Dataset:
  - QoE: startup delay, stall count
  - QoS: RTT, loss rate, throughput

- Baseline: **XGBoost**
- Prediction error: **5.5%** ▼
  - Clustering-based method is more **interpretable**.

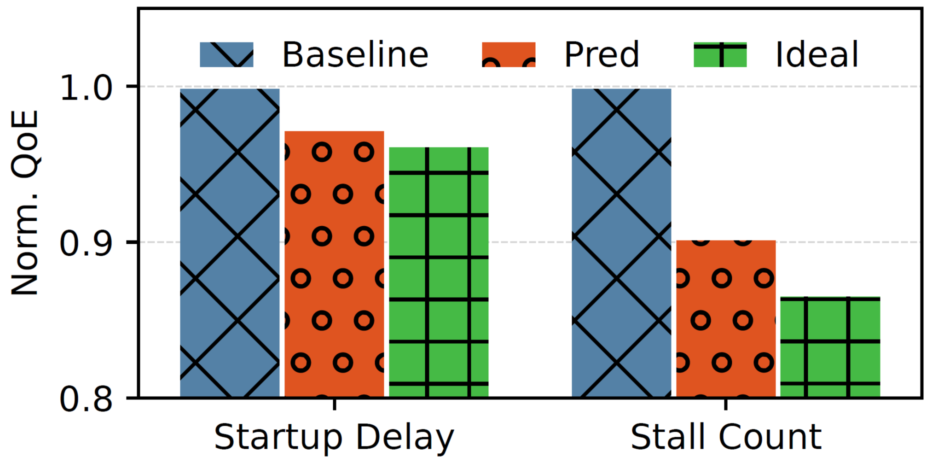
Cluster	1	2	3	4	5	6	7	8	AVG	XGBoost
Startup delay / %	3.2	2.3	2.3	2.8	3.2	2.5	4.4	2.5	**2.9**	**3.1**
Stall count / %	7.7	10.1	9.8	6.9	7.0	8.0	-	-	**8.3**	**8.7**

Comparison of Mean Absolute Prediction Error (MAPE)
for each clustering group, overall and XGBoost model.

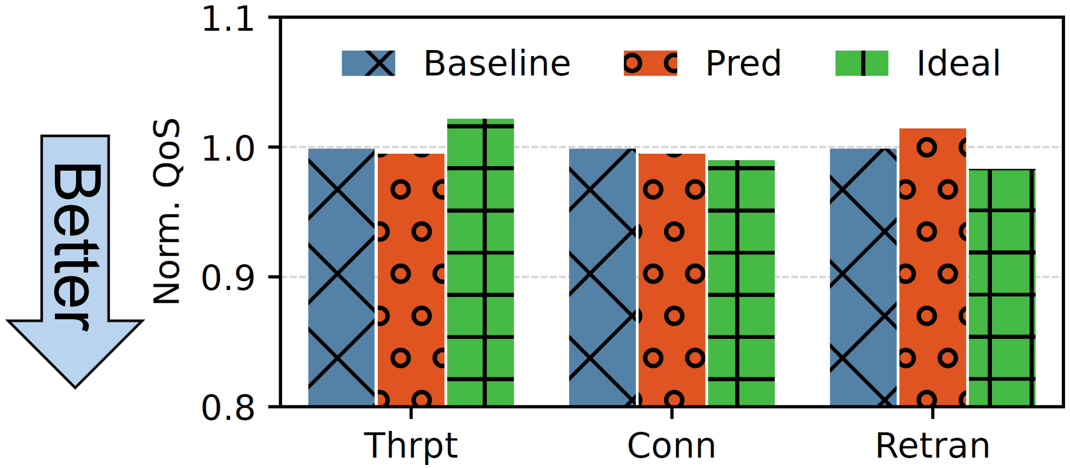
Evaluation: QoE-aware Scheduling

- Testbed: a simulation environment for CDN traffic scheduling
- Baseline: QoS-based scheduling
- Ideal: accurate QoE-aware scheduling (Optimal)

- QoE-aware scheduling achieves **9.9%** QoE ▲
  - under comparable QoS supplement.



Normalized QoE punishment.



Normalized QoS punishment.

Summary

- **Observation:** QoE and QoS are mismatched, and relationships are complex.
  - The mapping patterns are varied among different scenarios.

- **Solution:** a clustering-based prediction framework.
  - Accurately predicting the QoE performance from QoS metrics under different scenarios with interpretability.

- **Impact:** QoE-aware CDN scheduling
  - Providing additional QoE improvement under comparable QoS supplement.

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Thanks!

Q & A

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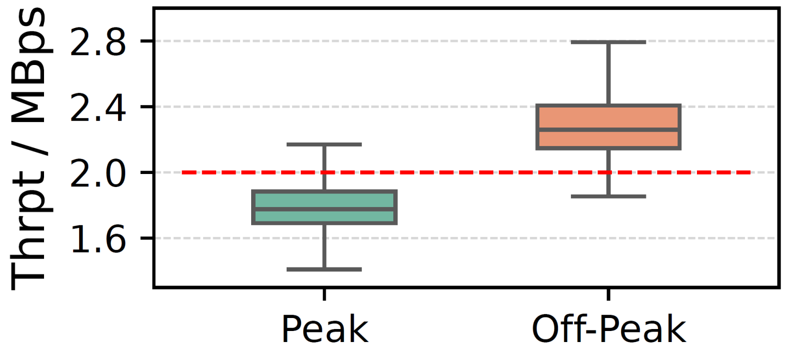
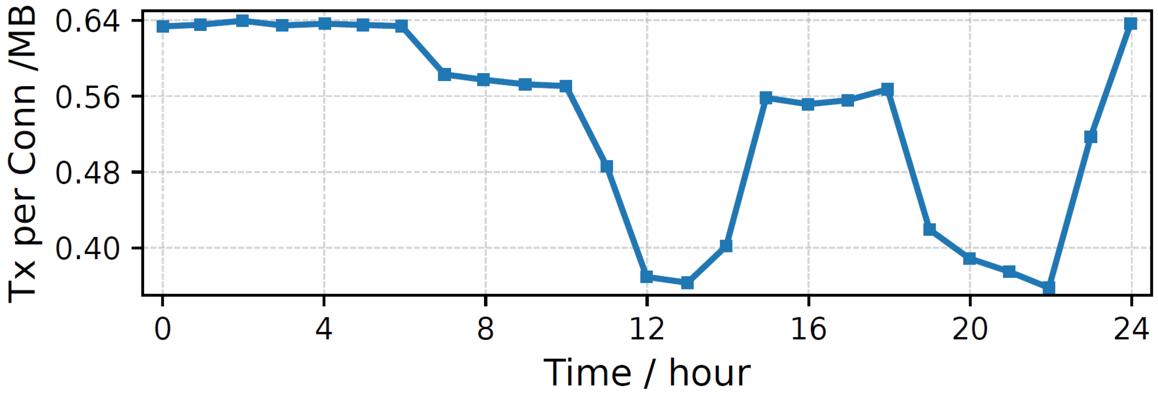
Appendix：
Resource Scarcity is the Key Differentiator

- Transition points widely exist.
  - $Thrpt_{tran} = \frac{Q_3(Thrpt_{peak})+Q_1(Thrpt_{off-peak})}{2}$
- Potential factors: user-side bit rate adaption strategies.



Throughput division in traffic peak (11h-14h, 19h-22h) and off-peak.



Mean amount of data transmission per TCP stream within a day.