SJA: Server-driven Joint Adaptation of Loss and Bitrate for Multi-Party Realtime Video Streaming

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Key Takeaways

Realtime multimedia traffic: 5% -> 17%

FEC -> Extra bandwidth can be leveraged for redundant coding

Global Optimization -> Overall QoE maximization of MRVS can only be achieved through server-driven approaches

Server-driven joint loss and bitrate adaptation framework in multiparty realtime video streaming services towards maximized global QoE.

This talk: Multi-party real-time video streaming services

Outline

- **Challenges** Unsatisfied QoE in multi-party realtime streaming services
- **Motivation** Global optimization for maximizing QoE
- **Solution** The SJA framework
- **Evaluation** Performance with Real-world Dataset

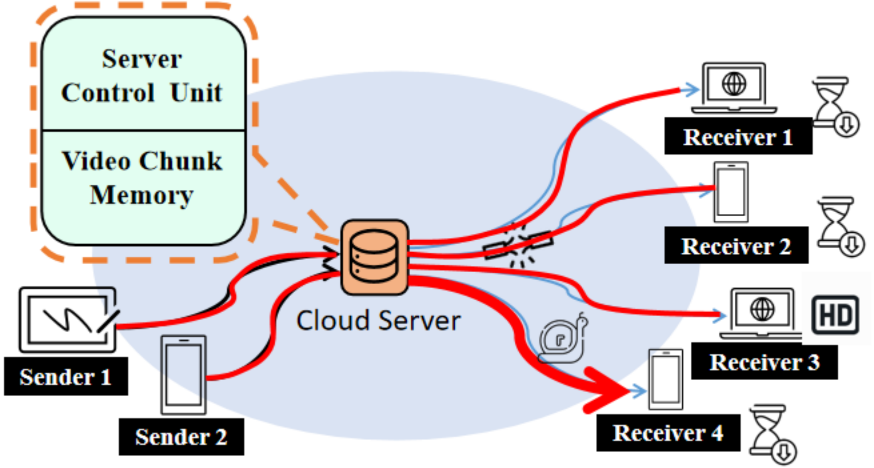
Unsatisfied QoE in Multi-party Realtime Streaming

Remote work

Online education

Entertainment

Unsatisfied QoE in Multi-party Realtime Streaming



1. Packet loss problem caused by unreliable transmission leads to delay increase and visual quality degradation.

2. Limited network resources problem arises in transforming from two-party to multi-party communication.

3. Coordinate the transmission behaviors of different parties to maximize the overall QoE.

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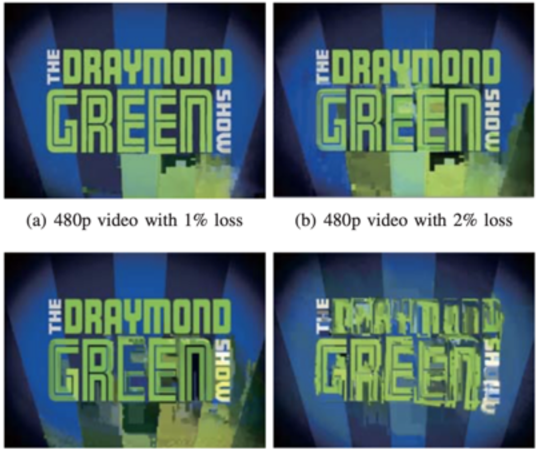
Insights

- The opportunity arises in comprehensively fine-tuning different QoE metrics (bandwidth, delay, video quality) to optimize user QoE in the multi-party real-time streaming system.

Insights

- Our insights :

1. Packets with bit error or packet loss can be ***tolerated*** at the expense of video quality to avoid retransmission and further improve QoE.



(a) 480p video with 1% loss (b) 480p video with 2% loss

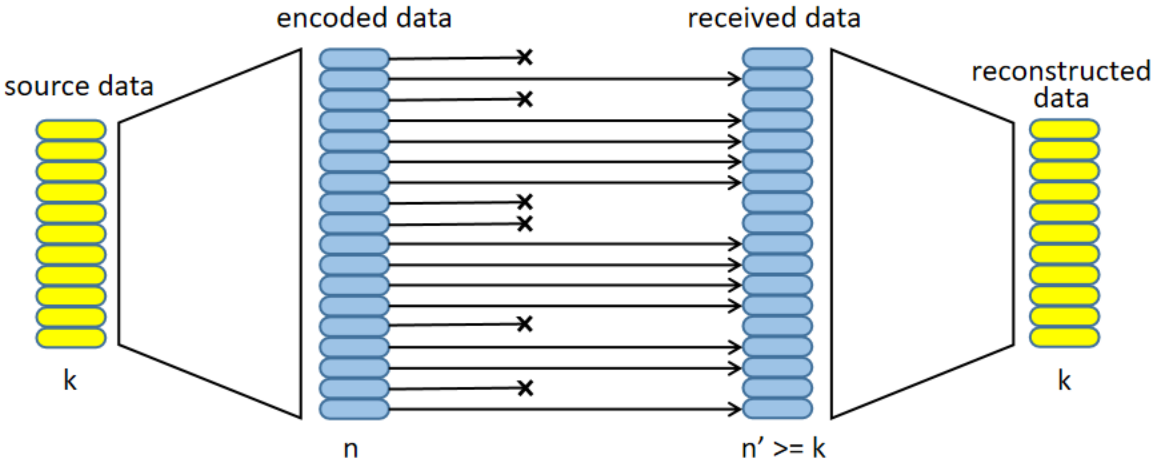
(c) 1080p video with 1% loss (d) 1080p video with 2% loss

Fig. 2. Visual effects when multiple viewers experience different loss rates.

Insights

- Our insights :

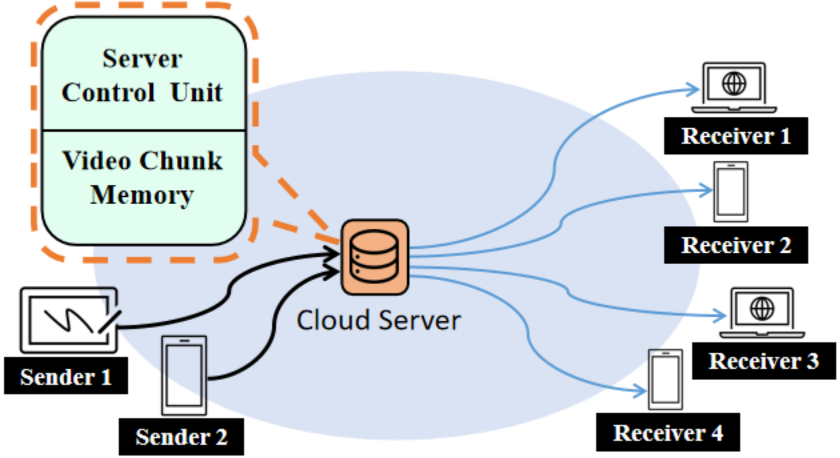
2. Extra bandwidth can be leveraged for redundant coding such that loss can be ***corrected*** without retransmission.



Insights

➢ Our insights :

3. Overall QoE maximization of MRVS can only be achieved through ***server-driven*** approaches.



Outline

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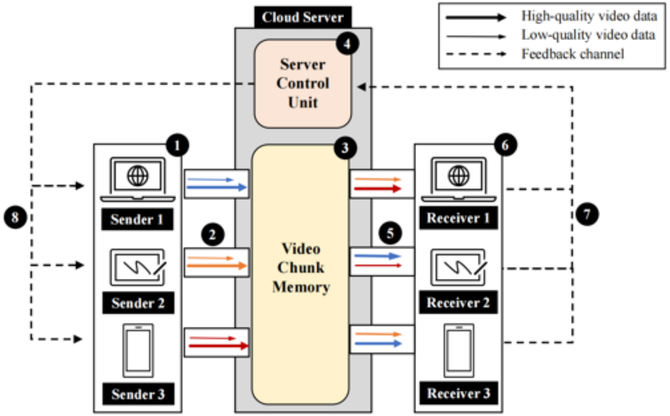
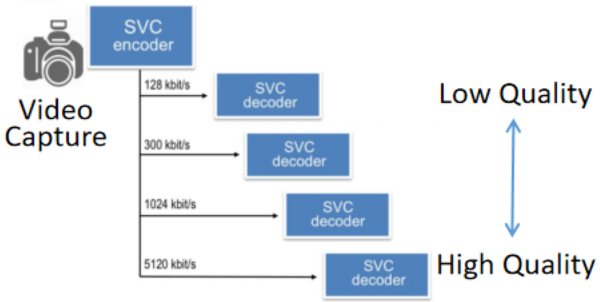
Motivation Global optimization for maximizing QoE

▶ **Solution** The SJA framework

Evaluation Performance with Real-world Dataset

The SJA Framework





1. Every Sender generates an uplink video stream
2. Multiple bitrate layers are uploaded to the video chunk memory in the cloud server
3. The cloud server does the orchestration.
4. The Server Control Unit in the cloud server collects state information and does the SJA algorithm, deciding bitrates and coding redundancy levels
5. Downlink streams are forwarded to corresponding receivers
6. Receivers play videos

7 8 Information feedback

Formulation of QoE maximization problem

$$QoE_j(k) = \sum_{i=1}^{I} \alpha_j^i \{ \beta_j q(r_k^{i,j}) - \gamma_j |q(r_k^{i,j}) - q(r_{k-1}^{i,j})| - \delta_j B(r_k^{i,j}, \hat{r}_k^{i,j}) - \epsilon_j d_{i,j}(k) - \zeta_j L(e_{i,j}(k)) \}$$

Bitrate; Bitrate Variation; Bitrate Mismatch; Delay; Bit errors

$$\max_{\{r_k^{i,j}, c_k^i\}} \quad \frac{1}{K} \sum_{k=0}^{K-1} \left[\sum_{j=1}^{J} \eta_j \cdot QoE_j(k) \right]$$

Time Average of All Users' QoE

$$s.t. \quad \max_j \{ \frac{r_k^{i,j}}{c_k^i} \} \le B_i^{up}(k), \forall i \in \mathbf{I}$$

Upload Constraint

$$\sum_{i=1}^{I} \frac{r_k^{i,j}}{c_k^i} \le B_j^{down}(k), \forall j \in \mathbf{J}$$

Download Constraint

$$\frac{1}{K} \sum_{k=0}^{K-1} d_{i,j}(k) \le \lambda T, \forall i \in \mathbf{I}, \forall j \in \mathbf{J}$$

Time-average Delay Constraint

$$r_k^{i,j} \in \mathbf{R}, c_k^i \in \mathbf{C}$$

Variables	Meaning
$r_k^{i,j}$	real bitrate from sender i to receiver j at time k
r_{min}	minimal bitrate level
$\hat{r}_k^{i,j}$	requested bitrate of sender i from receiver j at time k
$d_{i,j}(k)$	streaming delay between sender i and receiver j
c_k^i	FEC code rate of sender i at time k
$\mathbf{r}_k^i$	the set of all bitrates encoded by sender i at time k
$T(\mathbf{r}_k^i)$	encoding time of sender i at time k
$B_i^{up}(k)$	uplink bandwidth of sender i at time k
$B_j^{down}(k)$	downlink bandwidth of receiver j at time k
$p_i(k)$	loss rate between client i and the server at time k
$e_{i,j}(k)$	remaining loss rate from sender i to receiver j at time k
T	duration of each time slot

Lyapunov-based Relaxation

$$\max_{\{r_k^{i,j}, c_k^i\}} \quad \frac{1}{K}\sum_{k=0}^{K-1}\left[\sum_{j=1}^{J}\eta_j \cdot QoE_j(k)\right]$$
$$s.t. \quad \max_j\{\frac{r_k^{i,j}}{c_k^i}\} \leq B_i^{up}(k), \forall i \in \mathbf{I}$$
$$\sum_{i=1}^{I}\frac{r_k^{i,j}}{c_k^i} \leq B_j^{down}(k), \forall j \in \mathbf{J}$$
$$\frac{1}{K}\sum_{k=0}^{K-1} d_{i,j}(k) \leq \lambda T, \forall i \in \mathbf{I}, \forall j \in \mathbf{J}$$
$$r_k^{i,j} \in \mathbf{R}, c_k^i \in \mathbf{C}$$

Time-average Optimization Problem

$$\min_{\{r_k^{i,j}, c_k^i\}} \sum_{j=1}^{J}\left\{\sum_{i=1}^{I} Q_{i,j}(k)\left[d_{i,j}(k) - \lambda T\right] - V_j(\eta_j QoE_j(k))\right\}$$
$$s.t. \quad \frac{r_k^{i,j}}{c_k^i} \leq B_i^{up}(k), \forall i \in \mathbf{I}, \forall j \in \mathbf{J}$$
$$\sum_{i=1}^{I}\frac{r_k^{i,j}}{c_k^i} \leq B_j^{down}(k), \forall j \in \mathbf{J}$$
$$r_k^{i,j} \in \mathbf{R}, c_k^i \in \mathbf{C}$$

One-step Joint Adaptation Problem

One-variable subproblems with linear constraints

$$\min_{\{r_k^{i,j}, c_k^i\}} \sum_{j=1}^{J} \Big\{ \sum_{i=1}^{I} Q_{i,j}(k) \Big[d_{i,j}(k) - \lambda T \Big] - V_j(\eta_j QoE_j(k)) \Big\}$$

$$s.t. \quad \frac{r_k^{i,j}}{c_k^i} \leq B_i^{up}(k), \forall i \in \mathbf{I}, \forall j \in \mathbf{J}$$

$$\sum_{i=1}^{I} \frac{r_k^{i,j}}{c_k^i} \leq B_j^{down}(k), \forall j \in \mathbf{J}$$

$$r_k^{i,j} \in \mathbf{R}, c_k^i \in \mathbf{C}$$

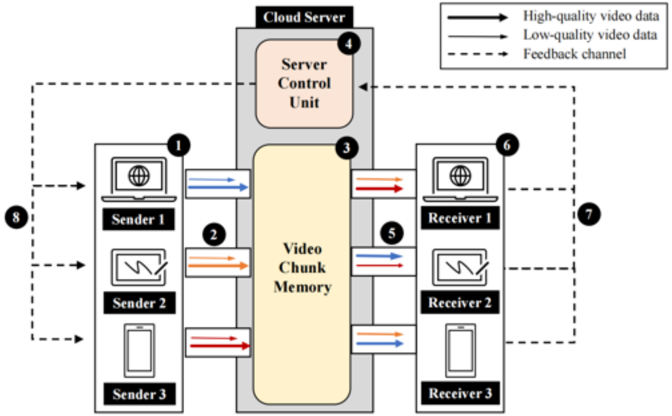
Master Problem

$$\begin{cases} f_0(\mathbf{r}_j, \mathbf{c}, k) = \sum_{i=1}^{I} Q_{i,j}(k) \Big[d_{i,j}(k) - \lambda T \Big] - V_j(\eta_j QoE_j(k)) \\ f_1(\mathbf{r}_j, \mathbf{c}, k) = \frac{r_k^{i,j}}{c_k^i} - B_i^{up}(k) \\ f_2(\mathbf{r}_j, \mathbf{c}, k) = \sum_{i=1}^{I} \frac{r_k^{i,j}}{c_k^i} - B_j^{down}(k) \end{cases}$$

$$\mathbf{r}_j^* = inf\{f_0 | f_n \leq 0, n = 1, 2\} \qquad (26)$$

Slave Problem

The SJA Framework



- Server-driven Control
- Redundant Encoding
- Lyapunov-based Relaxation
- Global QoE Optimization

Algorithm 1 SJA Algorithm for joint loss and bitrate adaption

Input:

Total times: K; Clients: $\mathbf{I}, \mathbf{J}$;
Bandwidth capacity: $B_i^{up}(k), \forall i \in \mathbf{I}$; $B_j^{down}(k), \forall j \in \mathbf{J}$;
Bitrate requests: $\hat{r}_k^{i,j}, \forall i \in \mathbf{I}, \forall j \in \mathbf{J}$;
Channel's loss rate: $p_i(k), \forall i \in \mathbf{I}, \mathbf{J}$;
Threshold: ζ; Maximum iterations: n;

Output:

Optimal bitrate and FEC code rate: $r_k^{i,j}, c_k^i$;

Initialize $Q_{i,j}(k)$, $i = 1, 2, ...I$, $j = 1, 2, ..., J$;
for $k = 1$ to K **do**
  Initialize $iteration = 0$, $\triangle = \infty$;
  while $iteration < n$ and $\triangle > \zeta$ **do**
    for all $i, \in \mathbf{I}, j \in \mathbf{J}$ **do**
      $r_k^{i,j} = \underset{\mathbf{r}}{inf}\{f_0 | f_n \le 0, n = 1, 2\}$;
      Update $\mathbf{r}_j$ to the master agent;
    end for
    for all $i \in \mathbf{I}, j \in \mathbf{J}$ **do**
      $r_k^{i,j} = \arg\min_{r \in \mathbf{R}} |f_0^j(r_k^{i,j}) - f_0^j(r)|$;
      $c_k^i = \arg\min_{c \in \mathbf{C}} \sum_{j=1}^{J} f_0^j(c)$;
    end for
    $\triangle = \sum_{j=1}^{J} f_0^j(k) - f_0^j(k-1)$;
    $iteration++$;
  end while
  Output joint adaption solutions $\mathbf{r}$ and $\mathbf{c}$ for time slot k;
end for

Slave Agent

Master Agent

The SJA algorithm

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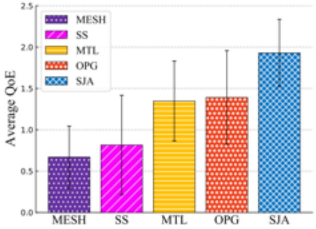
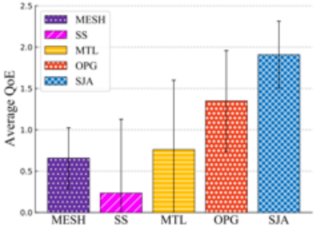
Evaluation

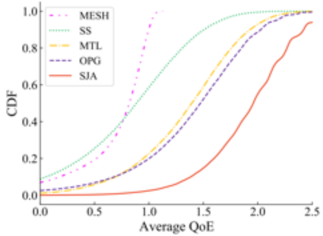
➢ Performance with Real-world Dataset:



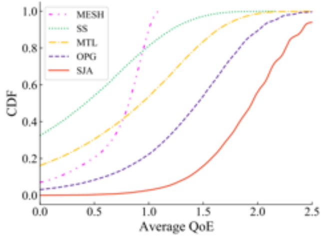
(a) The overall QoE over synthesized dataset with 1% loss



(b) The overall QoE over synthesized dataset with 2% loss



(a) CDF of QoE with 1% loss



(b) CDF of QoE with 2% loss

- ➢ SJA outperforms all the baselines with higher QoE
- ➢ SJA achieves more stable and concentrated QoE scores

Conclusion

- SJA: combines loss adaptation and bitrate adaptation with global QoE optimization.

- It uses server-driven architecture with Lyapunov-based Relaxation and SJA algorithm.

- Extensive trace-driven experiments confirm SJA's superiority with an 18.4% ~ 46.5% improvement.