Caching Policy Optimization for Rate Adaptive Video Streaming

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Introduction

Explosion of wireless data traffic

- **Main driver:** Video-on-demand (VoD)

Femtocaching

- Cache popular videos at helpers without backhaul link.
- Stream non-cached videos from macro BS.

Caching policy

- **Existing policy for file downloading service:** minimize the average file downloading delay.
- **Proposed policy for VoD service:**
  - maximize the average **QoE** of users with **video rate adaptation**
  - investigate how much portion of which video files should be cached at the helper with what video rates.

System Model

- **Consider a femtocaching system with one macro BS and one helper.**
- **The helper can cache videos, and the user can request videos from both macro BS and helper.**

Assumptions

- **Ideal backhaul at macro BS and infinite video quality levels.**
- **Processing capability of helper:** convert high quality level to lower levels.
- **Partial caching:** the helper can cache a part of a video.

Symbol definition

- $R_{B,u}$: downloading rate from macro BS to user u, and $R_{B,u}$ is larger than the minimal video playback rate.
- $R_{H,u}$: downloading rate from the helper to user u, and $R_{H,u} \geq R_{B,u}$.
- $R_{c,f}$: cached video rate of video f at the helper.
- $R_{p_*,uf}$: experienced playback rate of video f by user u for either cached or uncached part.
  - $*$: "c" for cached parts, "uc" for uncached parts.
- x_f: the cached portion of the video f.
- q_f: the request probability of the video f.
- T_f: the playback duration of the video f.
- C: the storage size of helper.
- QoE_{uf}: QoE of user u requesting the video f
  - $\text{QoE}_{uf} = x_f \text{QoE}_{c,uf} + (1-x_f)\text{QoE}_{uc,uf}$
  - **QoE model:** $\text{QoE}_{*,uf} = \alpha log(1+\beta R_{p_*,uf})$

Caching Policy Optimization

User-experienced Playback Rate

- **Cached part:**
  - Access to helper, $R_{p_c,uf} = \min\{R_{H,u}, R_{c,f}\}$.
  - Access to macro BS, $R_{p_c,uf} = R_{B,u}$.

  $\Rightarrow R_{p_c,uf} = \max\{R_{B,u}, \min\{R_{H,u}, R_{c,f}\}\}$.
- **Uncached part:** can only access macro BS, $R_{p_{uc},uf} = R_{B,u}$.

Single User Case

$$\max_{\{x_f, R_{c,f}\}_1^F} \alpha \sum_{f=1}^{F} q_f \left(x_f \log(1+\beta R_{p_c,f}) + (1-x_f)\log(1+\beta R_B)\right) \quad (1a)$$

$$s.t.\ R_{p_c,f} = \max\{R_B, \min\{R_H, R_{c,f}\}\},\ \forall f \quad (1b)$$

$$\sum_{f=1}^{F} x_f R_{c,f} T_f \leq C \quad (1c)$$

$$R_{c,f} \geq 0,\ \forall f \quad (1d)$$

$$0 \leq x_f \leq 1,\ \forall f \quad (1e)$$

- **(1a)**: maximizing the average QoE of the user where the average is taken over the random request to the F video files.
- **(1b)**: user-experienced playback rate for cached part.
- **(1c)**: constraint on the storage size of the helper.

Problem Solving

- $R_B \leq R_{c,f} \leq R_H$ in single user case $\Rightarrow R_{p_c,f} = R_{c,f}$ in (1b).
- Convert problem (1) into convex by defining auxiliary variable $z_f = R_{c,f} x_f,\ \forall f$.

Multiuser Case

$$\max_{\{x_f, R_{c,f}\}_1^F} \alpha \sum_{u=1}^{U} \omega_u \sum_{f=1}^{F} q_f (x_f \log(1+\beta R_{p_c,uf}) + (1-x_f)\log(1+\beta R_{B,u})) \quad (2a)$$

$$s.t.\ R_{p_c,uf} = \max\{R_{B,u}, \min\{R_{H,u}, R_{c,f}\}\},\ \forall u, f \quad (2b)$$

$$\sum_{f=1}^{F} x_f R_{c,f} T_f \leq C \quad (2c)$$

$$R_{c,f} \geq 0,\ \forall f \quad (2d)$$

$$0 \leq x_f \leq 1,\ \forall f \quad (2e)$$

- **(2a)**: maximize the weighted sum average QoE of multiple users, where ω_u is the priority weight associated with the user u.

Problem Solving

- **Fix user access strategy:** always access to the helper for the cached part $\Rightarrow R_{p_c,uf} = \min\{R_{H,u}, R_{c,f}\}$ in (2b).
- Convert problem (2) into convex by defining auxiliary variables $z_f = x_f R_{c,f}, y_{u,f} = x_f R_{p_c,uf}\ \forall u, f$.

Simulation Results

Simulation Setup

- Spectral efficiency of macro BS and helper: 3 and 5 bps/Hz.
- Bandwidth of macro BS and helper allocated to a video user: 0.2 and 2 MHz.
- Single user case: $R_B = 0.6$ Mbps, $R_H = 10$ Mbps.
- Multiuser case: $R_{B,u} \sim U(2, 20)$Mbps $R_{H,u} \sim U(0.2, \min\{10\ Mbps, R_{H,u}\})$.
- Requesting probability of 30 videos follows Zipf distribution with parameter=0.56.
- $\alpha = 1,\ \beta = 10,\ \omega = 1$.

Fig 1. Caching policies designed for VoD (marked by $*$) and file downloading (marked by $\triangle$), $C = 30$ Gbits, and T_f is 15, $(31-f)$ and $U(0,30)$ min for three columns.

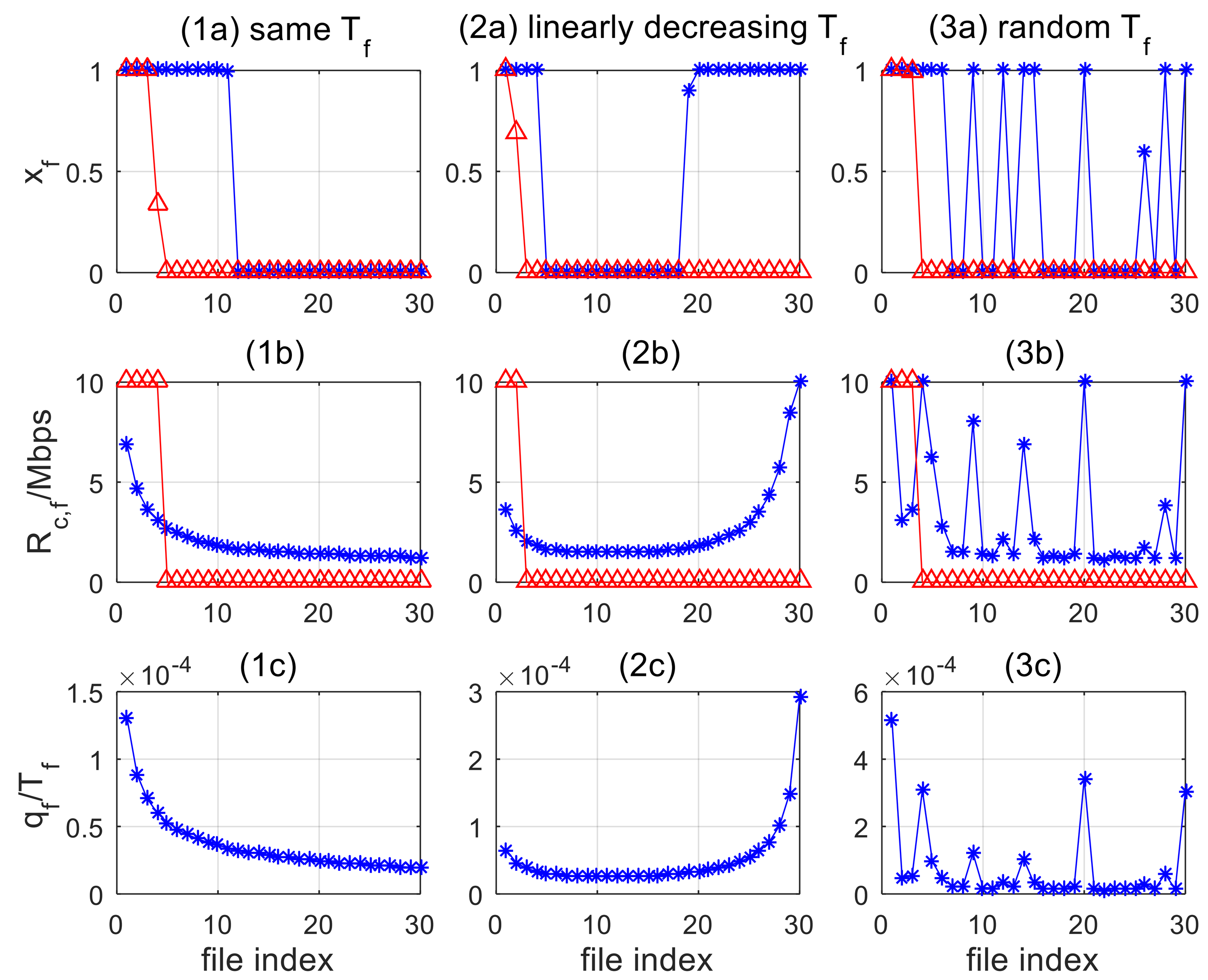

Fig 2. Average QoE under the two caching policies, $U = 10$ and $T_f \sim U(0, 30)$ min.