Modeling and Analysis of Peer-to-peer Video on Demand Streaming

Outline

- Characteristics of P2P VoD streaming
- Design Problems of P2P VoD streaming
- Modeling and analysis of P2P VoD streaming

Asynchronous playback

- Due to random arrival time, peers watch different parts of a video at the same time
  - In P2P live streaming, the peers have a shared temporal content focus
  - P2P-VoD has a greater temporal diversity of content requests
  - Require each peer to contribute an amount of storage (such as 1GB) to compensate the problem

VCR functions

- Users can offer control over the video streams with VCR operations: pause & resume; random seek
- VCR operations introduce more dynamics to overlay structures.
- Need mechanisms to support VCR

Design Problems

- Segment Sizes
  - Tradeoff between overhead and utility of upload capacity
- Replication Strategy
  - Increase content availability
  - Replication strategies: LRU, LFU; MVC, SVC; weight-based evaluation process
- Content Discovery and Peer Overlay Management
- Piece selection
  - Sequential
  - rarest first
- Transmission strategy

Models on P2P VoD

- Analysis of Piece selection
  - C. Williamson et al., "Analysis of BitTorrent-like Protocols for On-Demand Stored Media Streaming", SIGMETRICS'08
- Analysis of the effect of VCR functions
  - Zhen Wei Zhao et al., "Modeling the Effect of User Interactions on Mesh-based P2P VOD Streaming Systems", To be published in INFOCOM'11

Analysis of Piece Selection

- Assumptions:
  - Each peer is allowed U concurrent upload connections, D concurrent download connections, D>U.
  - Each connection achieves mean throughput C.
  - Not consider peer selection strategy. Assume peers can find needed contents.
  - Peers are cooperative

Analysis of Piece Selection

- Baseline model: Rarest-First
  - Fluid modeling approach
  - System efficiency η is taken as 1.
  - The change of downloader and seed population is:

$$\frac{dx}{dt} = \lambda - (x+y)UC,$$
$$\frac{dy}{dt} = (x+y)UC - \mu y.$$

  - The average number in steady-state:

$$\overline{x} = \lambda\left[\frac{1}{UC} - \frac{1}{\mu}\right] \qquad \overline{y} = \frac{\lambda}{\mu} \qquad T = \frac{\overline{x}}{\lambda} = \frac{1}{UC} - \frac{1}{\mu}.$$

Analysis of Piece Selection

- Strict In-Order Piece Selection (Random)
  - Peer relationships are asymetric: a given peer can only download from older peers, and can only provide content to younger peers
  - An uploader that receives more than U requests chooses at random U recipients for service. The remaining unsatisfied requests are purged from the system.

Analysis of Piece Selection

- Considering this, calculate the average downloading rate for a downloader.
  - The probability for a peer been in system for time t to obtain a download connection:

$$p(t) = \frac{\tilde{U}(t)}{\tilde{D}(t)} = \alpha \frac{(x + y - \lambda t)U}{xD}.$$

  - The average downloading rate:

$$\begin{aligned}
\gamma &= \frac{1}{T}\int_0^T Dp(t)C\,dt \\
&= \frac{1}{T}\int_0^T \alpha\left(\left(\frac{x+y}{x}\right)UC - \frac{\lambda t UC}{x}\right)dt \\
&= \alpha\left(\frac{x+y}{x}\right)UC - \alpha\frac{\lambda T UC}{2x} \\
&= \alpha UC\left[\left(1+\frac{y}{x}\right) - \frac{\lambda T}{2x}\right].
\end{aligned}$$

Analysis of Piece Selection

- The differential equation for number of downloaders and seeds is:

$$\frac{dx}{dt} = \lambda - \gamma x = \lambda - \alpha\left(\tfrac{1}{2}x + y\right)UC,$$

$$\frac{dy}{dt} = \gamma x - \mu y = \alpha\left(\tfrac{1}{2}x + y\right)UC - \mu y.$$

- The number can be obtained:

$$\overline{x} = 2\lambda\left[\frac{1}{\alpha UC} - \frac{1}{\mu}\right] \qquad \overline{y} = \frac{\lambda}{\mu} \qquad T = \frac{\overline{x}}{\lambda} = 2\left[\frac{1}{\alpha UC} - \frac{1}{\mu}\right]$$

Analysis of Piece Selection

- Insights:
  - The average download time almost doubles compared to Rarest-First. This is a large price to pay for the benefit of In-Order retrieval.
  - The number of downloaders in steady-state almost doubles compared to Rarest-First. The number of seeds remains the same as in Rarest-First.
  - Unlike the Rarest-First policy, the total swarm population depends on the seed residence time.

Analysis of Piece Selection

- Strict In-Order Piece Selection (FCFS)
  - A variant of the foregoing In-Order piece selection model: The requests for downloading are queued until they are serviced. The uploading peers don't purge the unfilled requests after each uploading round.
  - Finite queue + FCFS service model at uploading.
  - "Daisy-chain effect" is possible: peers of age t download their needed pieces from peers of age t+ϵ, and those peers in turn download their needed pieces from peers of age t+2ϵ, and so on.

Analysis of Piece Selection

- The differential equation for number of downloaders and seeds in this strategy:
  - Regardless of the actual peer relationships formed, all peers are busy uploading, therefor, the system efficiency is close to 1.
  - The steady-state swarm population and average download time is the same with the rarest-first model:

$$\bar{x} = \lambda \left[\frac{1}{UC} - \frac{1}{\mu} \right] \qquad \bar{y} = \frac{\lambda}{\mu} \qquad T = \frac{1}{UC} - \frac{1}{\mu}.$$

Analysis of Piece Selection

- Insights:
  - In-Order (FCFS) piece selection policy may achieve near optimal system efficiency and achieve download time identical to that of the rarest-first policy
  - In-Order (FCFS) provide ideal sequential progress at the peers.

Modeling the Effect of User Interactions

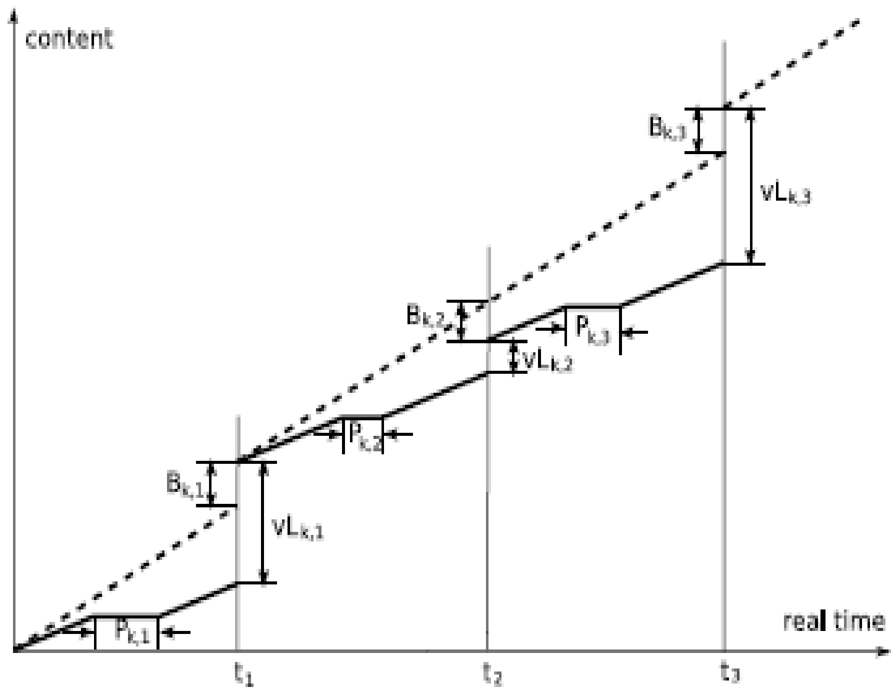
- Assumptions:
  - Ignore the peer overlay structure and piece selection strategy. Assume download rate is larger than video rate, $D>v$.
  - Peers adopt sequential prefetching.

Modeling the Effect of User Interactions

- Characterizing Seek and Pause
  - Seek distance (L): the amount of video time that a peer skips during a seek
  - Inter-seek distance (I): the amount of video time between two consecutive seeks.
  - Pauses: Type A: pauses that occur between two seeks; Type B: pauses that occur after the last seek.
  - All pauses that occur between two successive seeks into one aggregated pause

Modeling the Effect of User Interactions

Calculate the downloaded content under user interactions:



$$b_s = \lambda(z - \alpha bupt_s)$$

$$z = vl_v - \bar{N}\bar{G}$$

$$t_s = l_v - \bar{N}\bar{L} + \bar{N}\bar{P} + \bar{Q} + \xi c$$

$$G_{k,i} = -min(B_{k,i}, 0)$$

Modeling the Effect of User Interactions

$$B_{k,1} = (D_k - v)t_1 - vL_{k,1} + vP_{k,1}$$

$$B_{k,2} = \begin{cases} (t_2 - t_1)(D_k - v) - vL_{k,2} + vP_{k,2} & \text{if } B_{k,1} < 0 \\ (t_2 - t_1)(D_k - v) - vL_{k,2} + vP_{k,2} + B_{k,1} & \text{if } B_{k,1} \geq 0 \end{cases}$$

$$= (D_k - v)t_2 - min(B_{k,1}, 0) - v\sum_{j=1}^{2}(L_{k,j} - P_{k,j})$$

$$B_{k,3} = (D_k - v)t_3 - \sum_{j=1}^{2} min(B_{k,j}, 0) - v\sum_{j=1}^{3}(L_{k,j} - P_{k,j})$$

By generalization, we can get

$$B_{k,i} = (D_k - v)t_i - \sum_{j=1}^{i-1} min(B_{k,j}, 0) - v\sum_{j=1}^{i}(L_{k,j} - P_{k,j})$$

Modeling the Effect of User Interactions

- With

$$t_i = \sum_{j=1}^{i} (I_{k,j} + P_{k,j})$$

$$G_{k,i} = -min(B_{k,i}, 0)$$

- The generalized equation can be written as:

$$B_{k,i} = (D_k - v) \sum_{j=1}^{i} I_{k,j} + \sum_{j=1}^{i-1} G_{k,j} - v \sum_{j=1}^{i} L_{k,j} + D_k \sum_{j=1}^{i} P_{k,j}$$

Modeling the Effect of User Interactions

- Extend the Equation to a large number of peers:

$$\sum_{k=1}^{n_p} B_{k,N_k+1} = \sum_{k=1}^{n_p} \sum_{j=1}^{N_k+1} (D_k - v) I_{k,j} + \sum_{k=1}^{n_p} \sum_{j=1}^{N_k} G_{k,j} - v \sum_{k=1}^{n_p} \sum_{j=1}^{N_k+1} L_{k,j} + \sum_{k=1}^{n_p} \sum_{j=1}^{N_k+1} D_k P_{k,j}$$

- Simplify it by taking mean values:

$$\sum_{k=1}^{n_p} B_{k,N_k+1} = (n_s + n_p)(\bar{D} - v)\bar{I} + n_s \bar{G} - (n_s + n_p) v \bar{L} + (n_s + n_p) \bar{D} \bar{P}$$

Modeling the Effect of User Interactions

- We can get

$$\bar{G} = (1 + \frac{n_p}{n_s})(v\bar{L} - (\bar{D} - v)\bar{I} - \bar{D}\bar{P}) + \frac{n_p}{n_s}\bar{B}_{\bar{N}+1}$$
$$= v\bar{L} - (\bar{D} - v)\bar{I} - \bar{D}\bar{P} + \delta$$

$$\delta = \frac{1}{\bar{N}}(\bar{B}_{\bar{N}+1} - \bar{B}_1)$$

THANK YOU