# Analysis of Adaptive Streaming for CDN/P2P Live Video Systems

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# Introduction

- Author: A. Mansy and M. Ammar, from Georgia Institute of Technology.
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- Highlight: Build the model with existing models as building blocks.

# Significance

- Existing researches have explored
  - Adaptive streaming systems (mainly layered streaming)
  - Hybrid CND/P2P streaming systems
- respectively, but not yet explored the combination of the two.

# Definition

- Adaptive streaming (HTTP v.s. layered):
  - A video can be streamed at multiple qualities
  - Users can switch among different qualities
  - Download rate is assumed to be variable among clients but constant over time.
- Hybrid CDN/P2P
  - Users may receive data either from the server or other peers streaming the same quality of the same video

# System Architecture

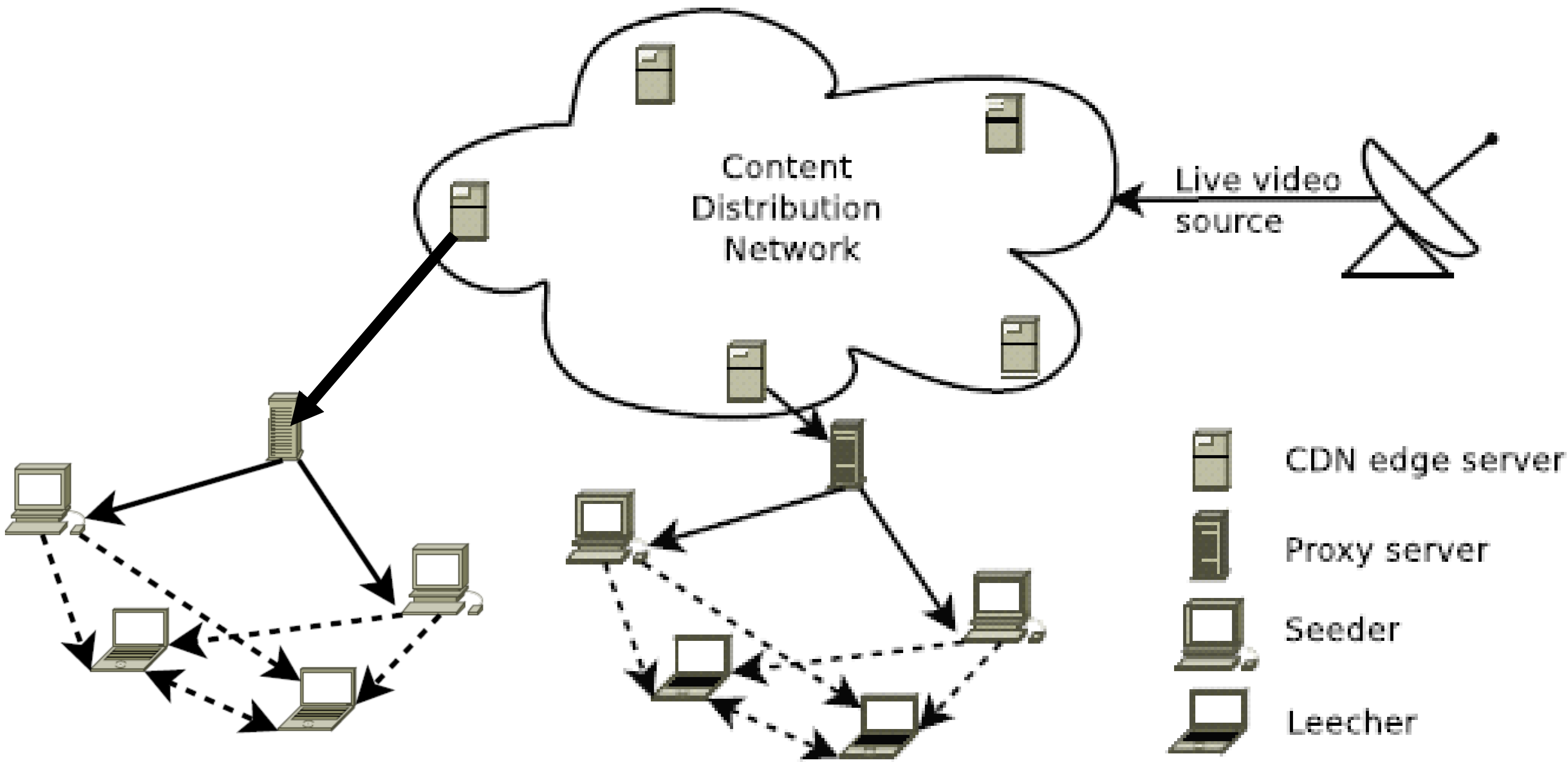



Fig. 1: System architecture

# Questions

- How to find a way to switch the operation of the system between the CDN and P2P modes
- How to find the best bitrate adaption strategy
- Is a hybrid adaptive system better than a classic CDN adaptive system? How much better will it be? (can not answer without a quantitative model)

# Approach: add dimensions one by one

- Hybrid system model with single rate
  - **Unconstrained churnless system (fluid model)**
  - **Unconstrained system with churn (M/G/∞ queueing model)**
  - Constrained churnless system
  - Constrained system with churn
- Adaptive hybrid system model
  - ...... (similar as the previous part)
- CDN adaptive model

# Single rate, unconstrained, churnless

- Relationship between
  - Streaming rate (or capacity of proxy server)
  - # of seeders and leechers
  - Bw. of seeders and of leechers

$$r \leq \frac{n_s u_s + n_l u_l}{n_l}$$

# Single rate, unconstrained, with churn

- The key is to find the probablity in terms of peer population
- M/G/∞

$$\begin{aligned} P(\text{support bitrate } r) &= P(r \leq \frac{n_s u_s + N u_l}{N}) \\ &= P(N \leq \frac{n_s u_s}{r - u_l}) = F(\frac{n_s u_s}{r - u_l}) \end{aligned}$$

- Relationship between streaming rate, # of seeders and leechers, bw. of seeders and of leechers

$$n_s \geq \frac{(\phi_{1-\alpha}\sqrt{\rho} + \rho)(r - u_l)}{u_s}$$

- Approximation:

$$\sqrt{\hat{\rho}} = a + b\hat{\rho}$$

# Single rate, constrained, churnless

- Avg. download bw. of leechers

$$
\begin{aligned}
d &= \sum_x E[d|\text{leecher is connected to } x \text{ seeders}] \times Pr\{x\} \\
&= \sum_x \left( \frac{x u_s}{S_{in}} + \frac{(Y_{out} - x)\eta u_l}{Y_{in}} \right) \times Pr\{x\} \\
&= \frac{\boxed{Y_{out}}\,\eta u_l}{Y_{in}} + \left( \frac{u_s}{S_{in}} - \frac{\eta u_l}{Y_{in}} \right) \boxed{\sum_x x Pr\{x\}} \qquad (4)
\end{aligned}
$$

$$Y_{out} = (n_s S_{in} + n_l Y_{in})/n_l$$

$$n_s S_{in}/n_l$$

- Therefore,

$$d = \frac{n_s u_s + \eta n_l u_l}{n_l}$$

- Compare with the results for churnless system

$$r \leq \frac{n_s u_s + n_l u_l}{n_l}$$

# Adaptive, unconstrained, churnless

- Proxy can offer multiple bitrates.
- Upon arrival, a client requests a bitrate and then the proxy assigns it a bitrate according to the optimization results.
  - The difference between the two is called "client dissatisfaction"
- The objective is to minimize total client dissatisfaction over all clients.

# Adaptive, unconstrained, churnless

- Mininze peers' dissatisfaction under capacity constraints

$$\min \sum_{i=1}^{R} \sum_{j=i}^{R} x_{ij} n_{l_i} (r_i - r_j) \qquad (7)$$

subject to: $\sum_{j=i}^{R} x_{ij} = 1$ , $0 \leq x_{ij} \leq 1$ for $i = 1, \ldots, R$

$$n_{s_i} u_s \geq \left( n_{l_i} x_{ii} + \sum_{k=1}^{i-1} n_{l_k} x_{ki} - n_{s_i} \right) (r_i - u_l) \qquad (8)$$

$$\sum_{i=1}^{R} n_{s_i} r_i \leq C_{proxy} \qquad (9)$$

$$r \leq \frac{n_s u_s + n_l u_l}{n_l}$$

- Observation:
  - Minimizing client dissatisfaction is equivalent to miximizing inter-client fairness

$$\sum_{i=1}^{R}\sum_{j=i}^{R} x_{ij} n_{l_i} r_i \left(1 - \frac{r_j}{r_i}\right) = \sum_{i=1}^{R} n_{l_i} r_i - \sum_{i=1}^{R} r_i \left( \sum_{j=i}^{R} n_{l_i} x_{ij} \frac{r_j}{r_i} \right)$$

# Feasibility

- Only if the system can support the lowest bitrate for all clients,

$$\frac{C_{proxy}}{r_R} \geq \frac{r_R - u_l}{u_s} \sum_{i=1}^{R} n_{l_i}$$

# Adaptive, unconstrained, with churn

- Relationship between streaming rate, # of seeders and leechers, bw. of seedrs and leechers

$$n_{s_i} u_s \geq (\phi_{1-\alpha/2}\sqrt{\hat{\rho}_i} + \hat{\rho}_i)(r_i - \eta u_l - \epsilon)$$

where $\hat{\rho}$ is defined as in the previous section.

# CDN adaptive

- Mininze peers' dissatisfaction under capacity constraints.

$$\min \sum_{i=1}^{R} \sum_{j=i}^{R} x_{ij} n_i (r_i - r_j)$$

- 

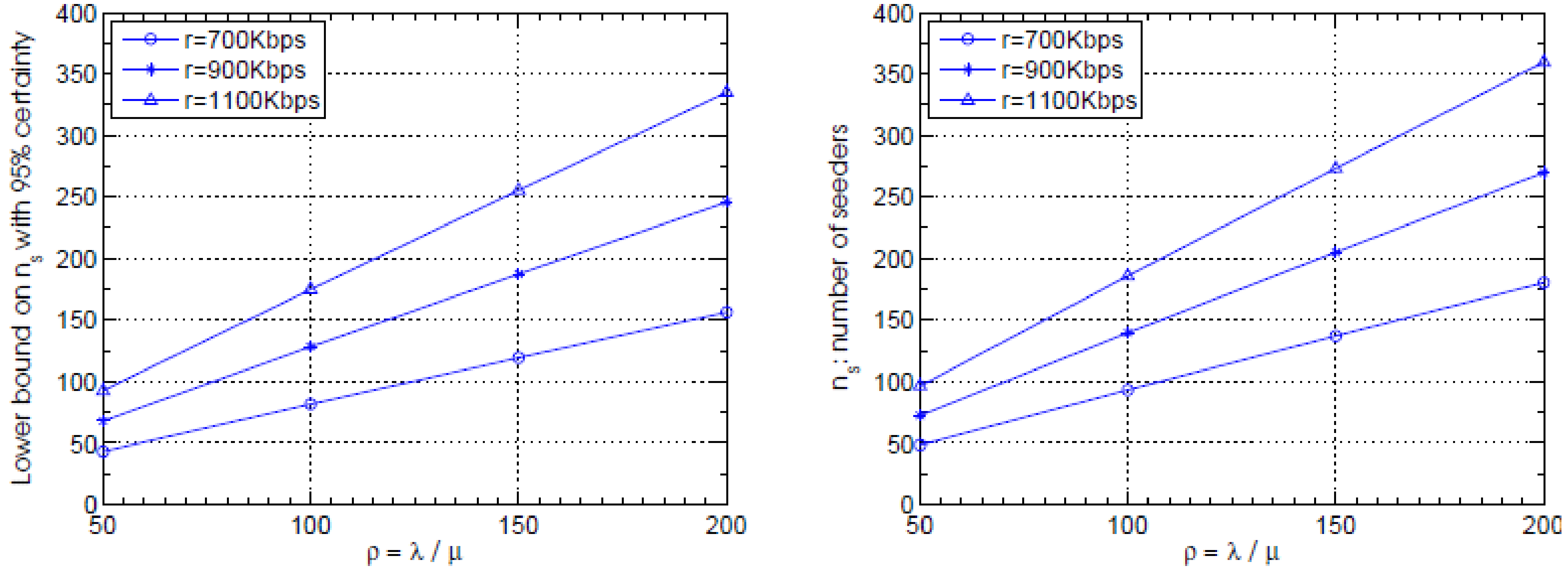
subject to: $\sum_{j=i}^{R} x_{ij} = 1$ , $0 \leq x_{ij} \leq 1$ for $i = 1, \ldots, R$

$$\sum_{i=1}^{R} r_i \left( n_i x_{ii} + \sum_{k=1}^{i-1} n_k x_{ki} \right) \leq C_e \qquad (12)$$

# Validation

- Validate single-rate model
  – compare results gained from fluid model and simulation. The accuracy of the whole model relies largely on the fluid model
- Validate the CDN adaptive model
- Fix bandwidth capacity and compare QoS
- Fix QoS and compare bandwidth savings

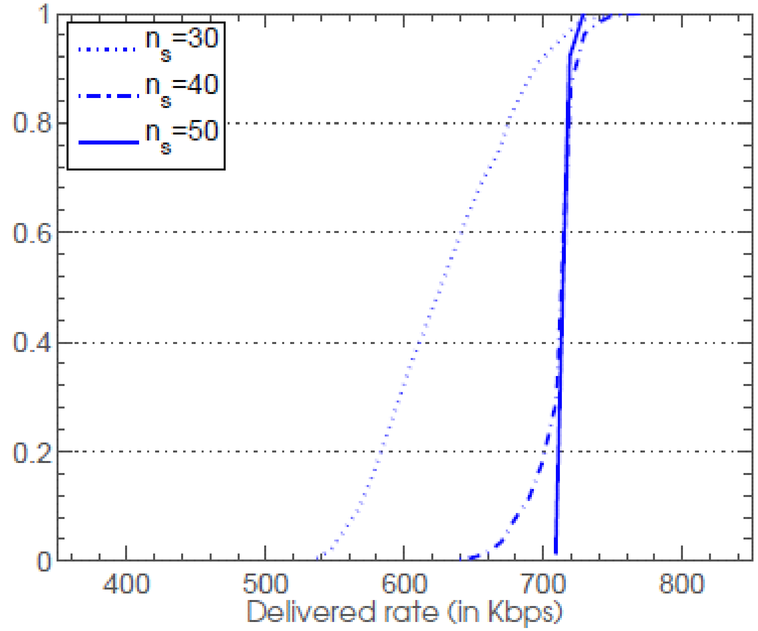
# Numerical results of single-rate model



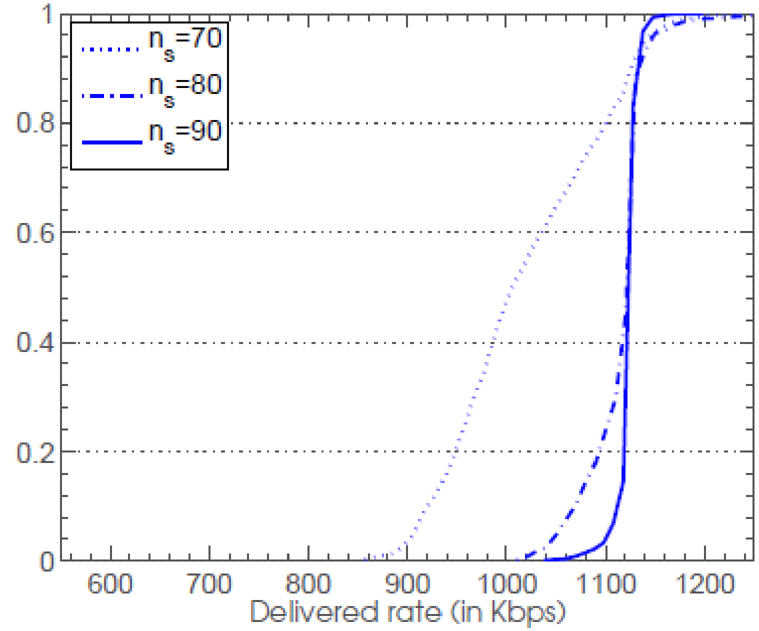

(a) Unconstrained system (b) Constrained system

Fig. 2: $n_s$ vs $\rho$ for different video bitrates for systems with churn, $\alpha = 0.05$

# Validate single-rate model




(a) $r = 700Kbps, \rho = 50$




(b) $r = 1100Kbps, \rho = 50$

Fig. 3: CDF of average delivered rate for unconstrained system with churn

# Validate single-rate model

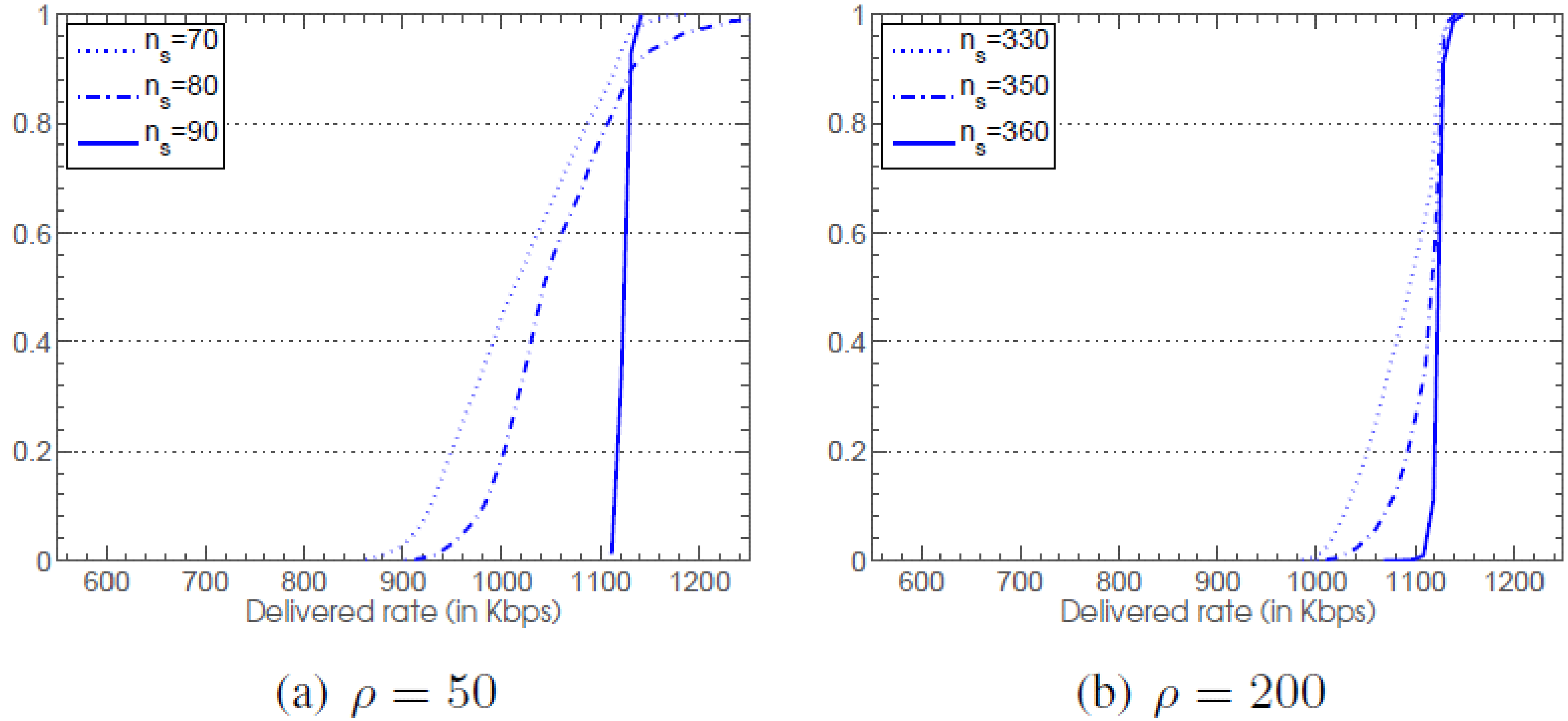
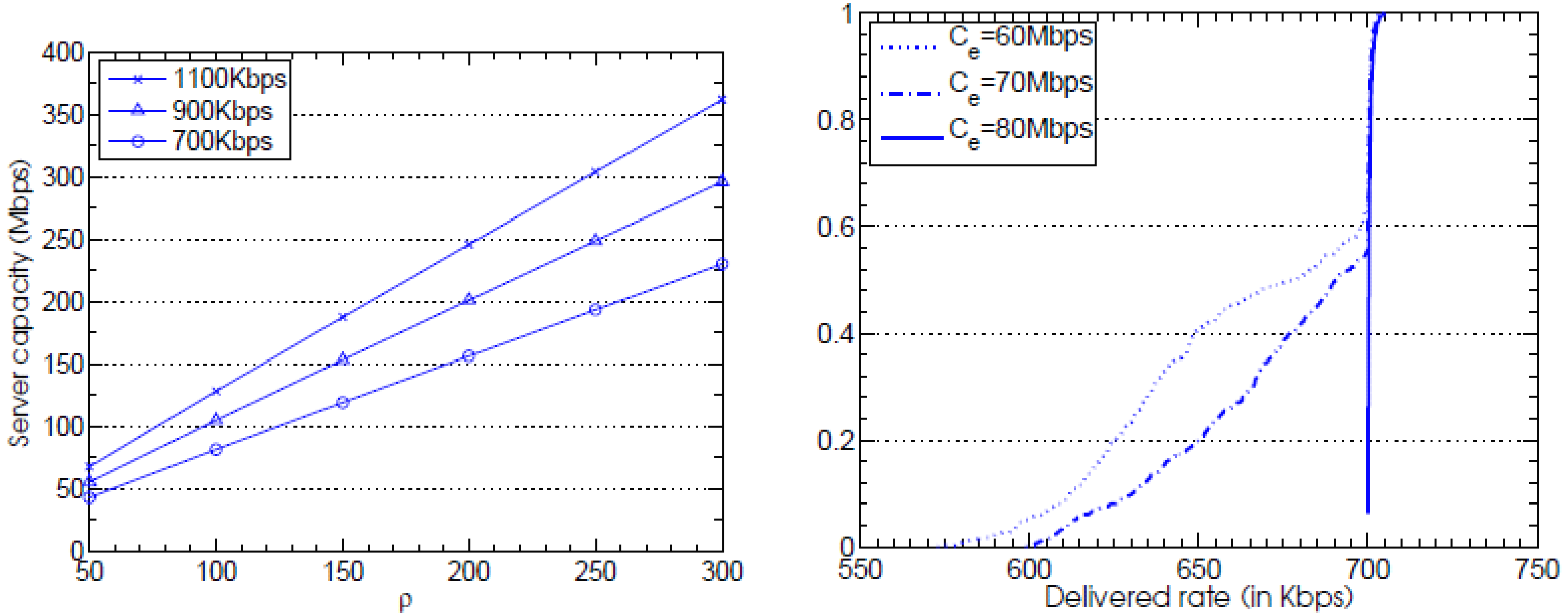



Fig. 4: CDF of average delivered rate for constrained system with churn, $r = 1100Kbps$

# Validate the CDN adaptive model

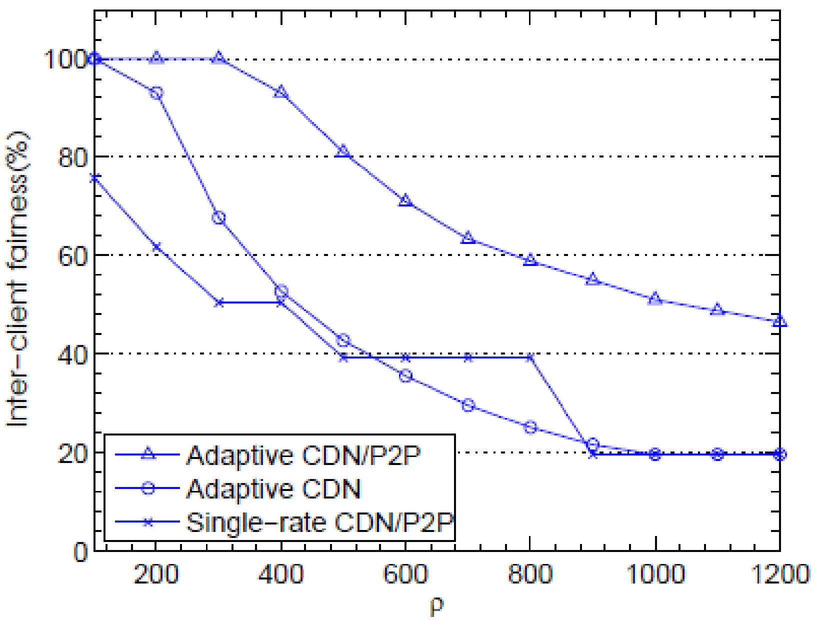



(a) Server capacity ($C_e$) vs $\rho$

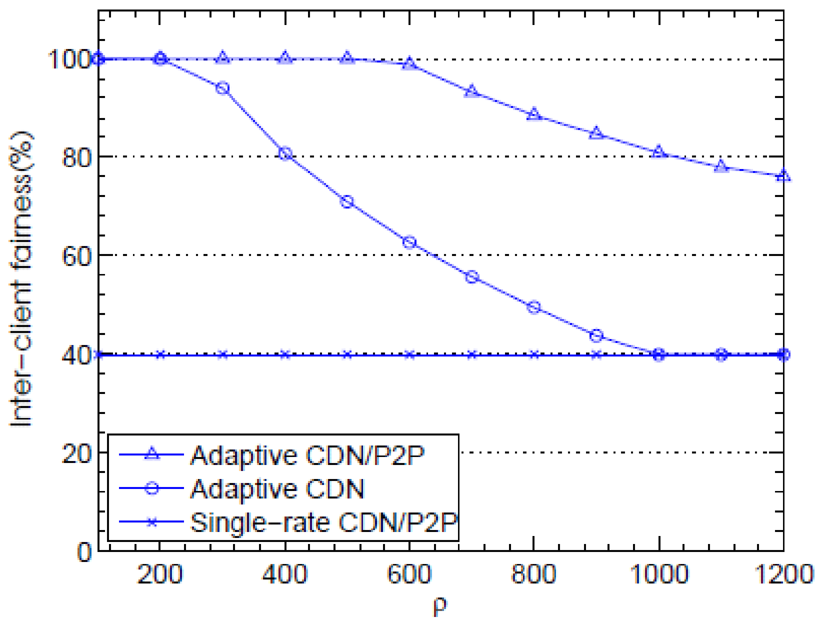
(b) $\rho = 100, r = 700$Kbps

Fig. 5: CDN system with churn

# Fix bandwidth capacity and compare QoS

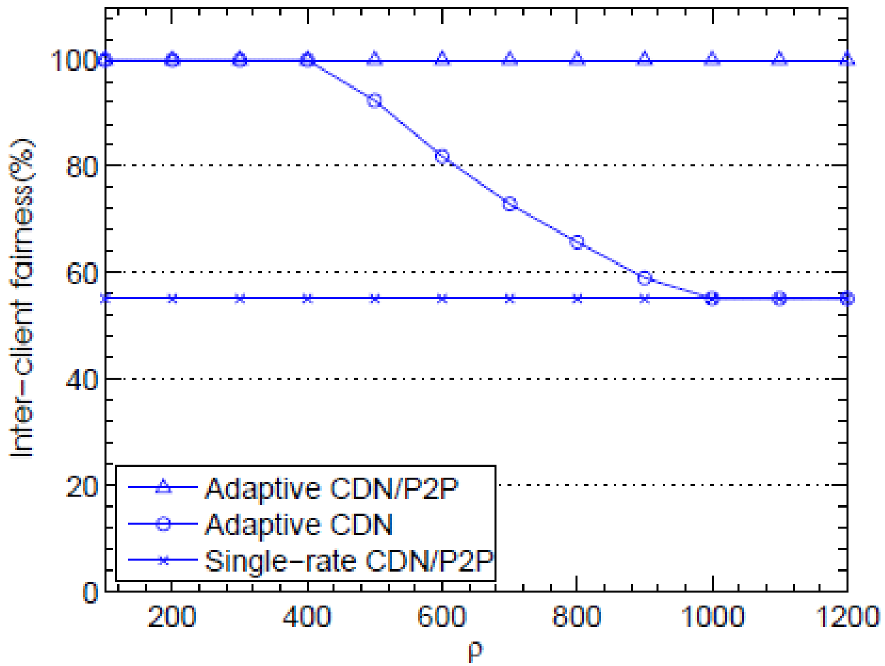



(a) High bitrate bias



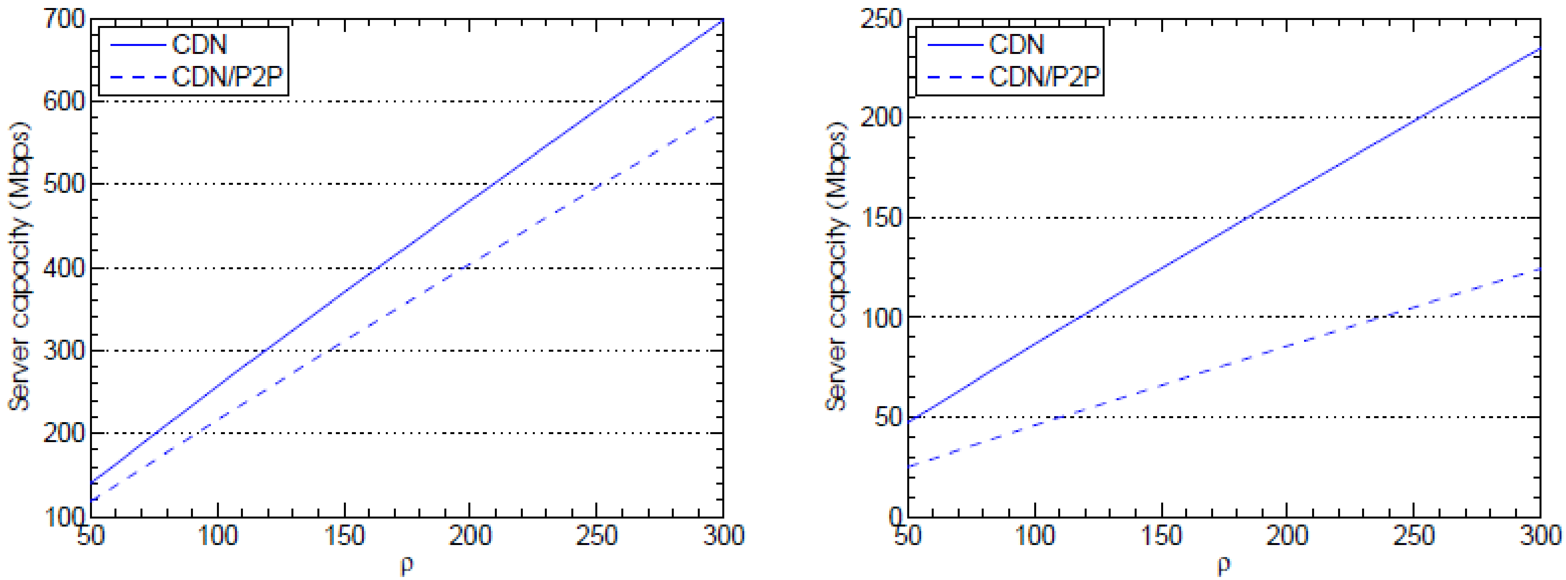

(b) Uniform distribution over bitrates

# Fix bandwidth capacity and compare QoS




(c) Low bitrate bias

# Fix QoS and compare bandwidth saving




(a) High bitrate bias (b) Low bitrate bias

Fig. 7: Required server capacity for CDN/P2P and CDN systems with churn

# Q & A

Thank you!