Contracts: Practical Contribution Incentives for P2P Live Streaming

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Introduction

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Principal Ways Where Contracts Differs from Existing Techniques

- A contract specifies an agreement between a client and the overall system
- Incentives for peers meet the global optimization requirements

Steps

1. Measurements show the limits of bilateral trading
2. *Contracts*

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Limits of Bilateral Exchange

- *Heterogeneity*
- *Limited bandwidth needs*
- *Limited trading opportunities*
- *Delay sensitivity*

- μ, σ: respectively denote the mean and variance of upload capacity
- S: the *skew* of upload capacity distribution, $S = \sigma/\mu$
- E: the efficiency, $E = r/\mu$, where r is the stream rate
- I: the imbalance, $I = \frac{1}{\mu}[\frac{\sum_i (x_i - r)^2}{N}]^{1/2}$

Theorem
High efficiency and high skew imply high imbalance. Specifically, (a) If peers upload at a rate proportional to their capacity, $I = E \cdot S$. *(b) For any feasible set of upload rates,* I *is bounded from below by a function that monotonically increases from* 0 *to* S *as* E *increases from* 0 *to* 1

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In live streaming, once a client is downloading data at the rate of production, a further increase in download rate is not possible

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Live streaming provides clients limited opportunities for mutually beneficial trading

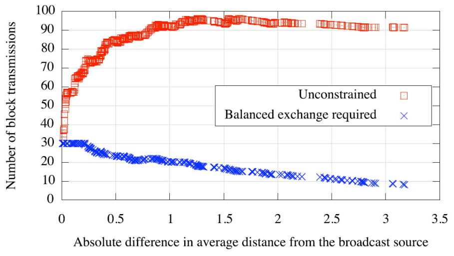

FIGURE: The impact of distance from the broadcast source on bilateral exchange. Requiring balanced exchange significantly limits trading opportunities as does distance from the source

Limits of Bilateral Exchange

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Theorem

Any topology in which a peer i has lower bandwidth than peer j but i has more descendants than j has higher average block delay than the topology obtained by swapping i and j if one of the following two conditions hold: (a) the topology is a balanced tree, or (b) i is an ancestor of j

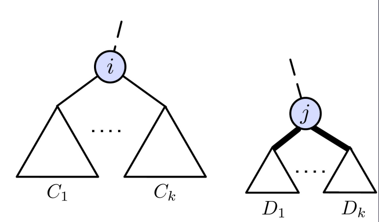

Figure: Illustration for Theorem **??**: Node j has higher upload capacity than node i but has fewer descendants

Structuring for Performance and Incentives

- High download rate *v.s.* robust playback quality
- Placing high capacity peers close to the source have two benefits
  - Overall playback quality
  - Local playback quality

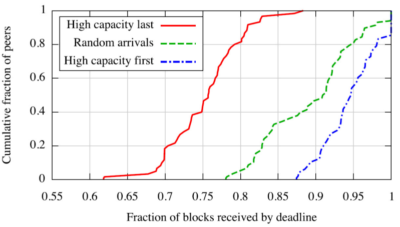

Figure: Cumulative fraction of clients with a given block delivery rate for different topologies. Placing high capacity clients near the source improves quality

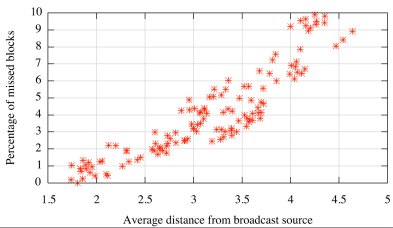

Figure: The fraction of blocks missing playback deadlines as a function of distance from the broadcast source. Playback quality is best for clients nearest to the source

Contracts

Design choices motivated by the considerations unique to live streaming

- Contracts rather than bilateral reciprocation

Contracts

Design choices motivated by the considerations unique to live streaming

- Contracts rather than bilateral reciprocation
- Global topology optimization

Contribution Contracts

Performance metrics:

- $B(x \rightarrow y)$: the contribution rate from x to y
- $B(x)$: the total rate contributed by node x
- $BC(x)$: the discrete classes mapped from $B(x)$ – the deciles of the observed capacity distribution from PPLive

Contribution Contracts (cont.)

$I(x)$ is the one-hop propagation of x's contributions:

$$I(x) = \sum_{p \in peers(x)} B(x \rightarrow p) \cdot D_{BW}(BC(p))$$

$D_{BW} \in [0,1]$ is a weight specified by the cumulative distribution function of peer upload capacities

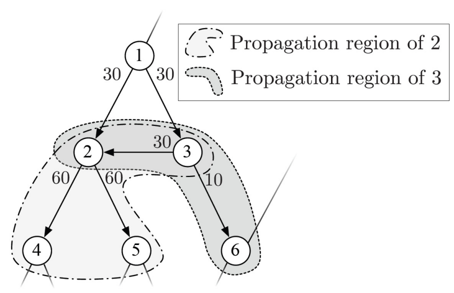

Figure: Evaluation I for client 1. Contribution from $1 \rightarrow 2$ is weighted by rates from $2 \rightarrow 3, 4, 5$. Contribution of $1 \rightarrow 3$ is weighted by the rates from $3 \rightarrow 2, 6$

Contribution Contracts (cont.)

Global evaluation function $V(x)$ with comparison operator:

$$V(x) > V(y) \iff \begin{array}{l} BC(x) > BC(y) \text{ or} \\ BC(x) = BC(y) \text{ and } I(x) > I(y) \end{array}$$

- *Peer selection*: Each node selects the top k peers by rank-ordering their $V(\cdot)$ values
- *Block request servicing*: Each client prioritizes requests with the maximum $B(\cdot)$ value

Limits of Bilateral Exchange

Structuring for Performance and Incentives

Contracts

- Contribution Contracts
- Topology Updating Policy

Evaluation

Conclusion

Topology Updating Policy

- Incentive-aware gossip
- Bootstrapping new clients
- Verifying contributions
- Collusion resistance

- Each client is aware of the capacities $BC(\cdot)$ of its one-hop neighbors
- It sorts $p \in (Peers \circ Peers)(c)$ by $BC(p)$, and connects to them in descending order

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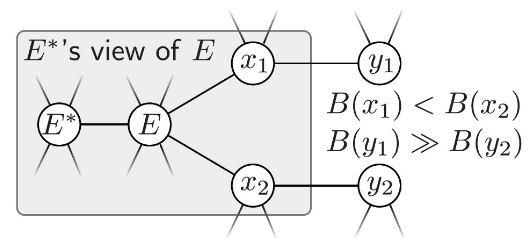

FIGURE: Suppose $BC(y_1) > BC(x_1)$, E would increase its V-value by sending to y_1 directly rather than through x_1

Topology Updating Policy

- Incentive-aware gossip
- Bootstrapping new clients
- Verifying contributions
- Collusion resistance

- New clients are typically placed far from the data source and overlooked
- Contracts clients advertise a *bootstrapping block* to inform excess capacity
- The probability of requesting bootstrapping blocks: $1 - \frac{\text{Peers with excess capacity}}{\text{Total peers}}$

Topology Updating Policy

- Incentive-aware gossip
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- P sends Q a receipt containing $< N_Q, K_P \rightarrow K_Q : V >_{K_P}$
- Receipts are used to verify the contribution in both distributed and centralized manners

Topology Updating Policy

- Incentive-aware gossip
- Bootstrapping new clients
- Verifying contributions
- Collusion resistance

- Limited identity creation
- Flow integrity check
- Global and diversity weighting

Performance and Incentives

Performance

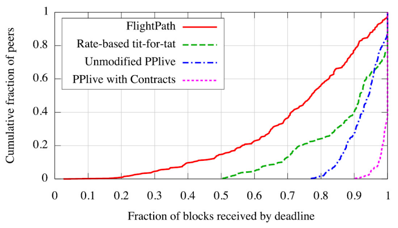

Figure: Performance comparison of unmodified FlightPath, PPLive, rate-based tit-for-tat, and Contracts

Incentives

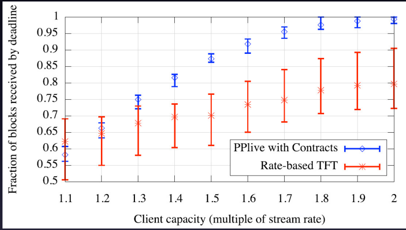

Figure: Delivery rate as a function of contribution

Convergence

- *Client capacity*: Low capacity peers can quickly discover the stable matchings, while high capacity peers need several rounds to stabilize
- *The number of clients*: The number of rounds increases logarithmically with the number of joining peers

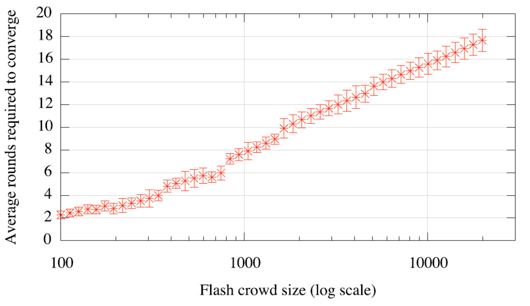

Figure: The number of peer exchanges required for a set of newly joined clients to reach stable places in the topology

Limits of Bilateral Exchange

Structuring for Performance and Incentives

Contracts

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Evaluation

Conclusion

Conclusion

Peer resource (upload capacity)

$\Downarrow$

Robust playback quality

$\Downarrow$

Topology optimization

Thanks

The end, thank you.

Theorem 1

$$
\begin{aligned}
E \cdot S &= \frac{r}{\mu^2}\sigma \\
&= \frac{r}{\mu^2}[\sum_i \frac{1}{N}(c_i - \mu)^2]^{1/2} \\
&= \frac{1}{\mu}[\sum_i \frac{1}{N}(\frac{c_i^2}{\mu^2}r^2 + r^2 - 2\frac{c_i}{\mu}r^2)]^{1/2} \\
&= \frac{1}{\mu}[\sum_i \frac{1}{N}(\frac{(f \cdot x_i)^2}{\mu^2}r^2 + r^2 - 2\frac{f \cdot x_i}{\mu}r^2)]^{1/2} \\
&= \frac{1}{\mu}[\sum_i \frac{1}{N}(x_i^2 + r^2 - 2x_i r)]^{1/2} \\
&= I
\end{aligned}
$$

$$
f = \frac{c_i}{x_i} = \frac{\mu}{r}
$$