Stochastic Model for ISP-aware VoD

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Introduction

Content distributors apply peer-to-peer technology in Video-on-Demand systems, e.g., PPLive, UUSee, to alleviate the heavy workload of servers in data centers. When distributed peers' storage and upload bandwidth resources are exploited in P2P technology, it increases the cross-ISP traffic inevitably. A large volume of the cross-ISP traffic is unnecessary due to the ISP-agnostic P2P connections, which increases the cost of ISPs. This makes ISPs start to proactively detect and throttle P2P data packets, which definitely affects the service quality.

This paper aims at solving the tussle between ISPs and content distributors. We first analyze under what situations VoD systems achieve the minimum chunk loss probability. We analyze the ISP-aware peer selection strategy when minimizing the chunk loss probability.

Model Framework

Loss network model for VoD:
The basic loss network model reflects the loss probabilities of calls on different routes, which require a set of links to serve a call.

In VoD systems, the requests for different chunks correspond to the calls on different routers, the peers with different cache states correspond to different links. Peers' upload bandwidth correspond to the circuits of a link. The requests for a chunk can link to peers caching the chunk for service.

How to calculate the loss probability?

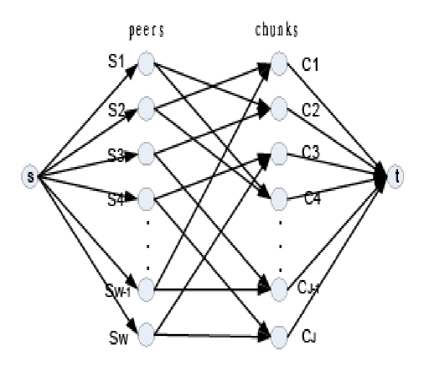
According to the 1-point approximate algorithm, we just consider the state with the maximum probability in the loss network as an approximation.

$$L_m = 1 - \frac{\sum_{j=1}^{J} x_{m,j}}{v_m}$$

$x_m = \{x_{m,j}\}$ is the state of served chunk requests with the maximum probability. v_m is the total chunk request rate in ISP m. L_m is the chunk loss probability in ISP m.

We use a maximum bipartite flow graph to calculate the state with the maximum probability.

Theorem 1: The total served request chunks with the maximum probability, $\sum_{j=1}^{J} x_{m,j}$, is the maximum bipartite flow of the corresponding bipartite graph.



Hence, for general chunk request rates and general peer cache state distribution, we can obtain the chunk loss probability by solving the maximum bipartite flow.

Optimal Cache Distribution

What is peers' optimal cache distribution for VoD systems to achieve the minimum chunk loss probabilities?

First, the minimum chunk loss probability is determined by peers' total upload bandwidth and the total chunk requests. For ISP m,

$$L_{\min} = \min\{1 - \frac{N_m \cdot U_m}{v_m}, 0\}$$

Lemma 1: Under different peer upload bandwidth allocation strategy, the corresponding optimal cache distribution is different. When peers allocate the upload bandwidth among cached chunks proportional to chunk request rate, the optimal cache distribution is that the proportion of cache state S_i is:

$$\gamma_i = \frac{\sum_{c_j \in S_i} v_{m,j}}{C_{J-1}^{B-1} v_m}$$

$v_{m,j}$ is the chunk request for chunk j in ISP m.

When peers allocate their upload bandwidth uniformly among cached chunks, the optimal cache distribution is that the proportion of peers caching chunk c_j is:

$$\rho_j = B \cdot \frac{v_{m,j}}{v_m} = B \cdot \pi_j$$

B is the size of peers' cache. π_j is the popularity of chunk j.

We analyze peers' cache stationary states of LRU (Least Recently Used) algorithm. We find that the stationary states can achieve the second optimal cache distribution in Lemma 1.

ISP-aware Request Routing

We try to achieve the minimum chunk loss probability in VoD systems, simultaneously, we explore an ISP-aware chunk request routing, which will reduce the cross-ISP traffic.

We consider two cases separately:

(1) When peers' total upload bandwidth is larger than the total demand of chunk requests, the chunk request routing strategy should satisfy that the upload bandwidth in some ISP can serve the chunk requests routed into it.

$$\sum_{l=1}^{M} a_{lm} r_l \le U_m N_m, 1 \le m \le M$$

$$\sum_{m=1}^{M} a_{lm} = 1, 1 \le m \le M$$

a_{lm} is the proportion of chunk requests routed from ISP l to ISP m. r_l is the chunk requests generated in ISP l.

(2) When peers' total upload bandwidth is smaller than the total demand of chunk requests, the chunk request routing strategy should satisfy that the upload bandwidth in any ISP can not serve all the chunk requests routed into it.

$$\sum_{l=1}^{M} a_{lm} r_l \ge U_m N_m, 1 \le m \le M$$

$$\sum_{m=1}^{M} a_{lm} = 1, 1 \le m \le M$$

Hence, we just need to distribute the chunk requests based on the two above inequalities. We find a feasible strategy is that peers select the number of neighbors from different ISPs proportionally to peers' total upload bandwidth. When d is the total number of a peer's neighbors, the number of neighbors from ISP m is:

$$\frac{U_m N_m}{\sum_{k=1}^{M} U_k N_k} \cdot d$$

Under the optimal cache distribution and ISP-aware request routing, we can obtain the chunk loss probability in each ISP. Hence, we can calculate the cross-ISP traffic as follows:

$$T_m^i = \sum_{l=1, l \ne m}^{M} a_{ml} \cdot r_m \cdot (1 - L_l)$$

$$T = \sum_{m=1}^{M} T_m^i$$

Conclusion

This paper targets theoretical study of ISP-aware peer selection strategy under minimizing the chunk loss probability. We analyze simple strategies, LRU and ISP-aware random peer selection strategy. We show that these simple strategies can achieve the minimum chunk loss probability, simultaneously are ISP-friendly.

References

(1) F. Kelly, "Loss Network", The Annals of Applied Probability, vol. 1, no. 3, pp. 319-378, Aug. 1991.

(2) B. R. Tan and L. Massoulie, "Optimal Content Placement for Peer-to-peer Video-on-Demand Systems", in Proc. of IEEE INFOCOM, April 2011.