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P2P (Peer-to-Peer) 비디오 스트리밍을 위한 다중 비디오 품질 인센티브 기법

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요 약

인터넷 상에서의 비디오 스트리밍을 위한 대안으로서 P2P(Peer-to-Peer)가 관심을 받고 있다. P2P 시스템은 피어들의 대역폭 기여에 의존하고 있지만, 피어들은 자신의 대역폭을 제공하는 것을 꺼리는 경향이 있다. 본 논문에서 우리는 상향 대역폭 기여를 촉진하는 P2P 스트리밍 시스템을 제안한다. 제안 시스템에서 피어들 간의 공평성을 유지하고, 제어 가능한 방법으로 협력적인 피어와 이기적인 피어에게 다른 품질의 비디오를 제공한다. 제안 시스템은 기여한 상향 대역폭에 기초한 평가 기법으로 피어가 협력적인지 이기적인지를 결정하고, 협력적인 피어들에게는 인센티브로서 고품질의 비디오를 제공한다. 또한 제안시스템이 효과적으로 동작할 수 있도록 트리 재건조 알고리즘을 제안한다. 시뮬레이션을 통해, 트리 재건조 알고리즘이 효과적으로 동작하며, 인센티브 기법이 협력적인 피어에게 더 많은 하향 대역폭을 할당하고 이기적인 피어에게는 저품질 비디오를 제공함을 보인다.

키워드 : 비디오 스트리밍, 피어-투-피어, 인센티브 기법

Layered Video Quality Incentive Mechanism for Peer-to-Peer Video Streaming

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ABSTRACT

Peer-to-Peer (P2P) has attracted attention as an alternative way to enable streaming videos on the Internet. Although P2P systems depend on bandwidth contribution from peers, peers are likely to refuse to contribute their bandwidth. In this paper, we proposed a P2P streaming system that encourages peers to contribute their upstream bandwidth by maintaining fairness among peers and providing different video quality between cooperative peers and selfish peers with a manageable way. Our proposed system determines if peers are cooperative or selfish by a rating mechanism based on their contributed upstream

bandwidth, and offers a high quality video to cooperative peers as an incentive. Also we propose a tree reconstruction algorithm to make the system work effectively. Through simulation, we show that the tree reconstruction algorithm works effectively, and our incentive mechanism allocates more downstream bandwidth to cooperative peers and punished selfish peers with low quality video.

Keywords : Video Streaming, Peer-to-Peer, Incentive Mechanism

1. Introduction

Video streaming over Internet has drawn a lot of interest from researchers in recent decade. Peer-to-Peer(P2P) has become an alternative way to enable broadcasting video on the Internet [1, 2]. P2P system works on premise that every peer contributes their upstream bandwidth and transmits video data to others. If a significant fraction of peers refuse to contribute, then P2P system would not work [3]. Currently, there are already some P2P video streaming services such as PPLive [4], PPStream [5], and UUsee [6].

There are some opportunities and challenges in building P2P video streaming system [7]. Challenges include choosing a P2P architecture, tree-based or data-driven architecture, handling free rider phenomenon, maintaining fairness among

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peers, facing heterogeneity in peers bandwidth, and so on. Some challenges are still open problems that researches have attacked. Many P2P video streaming systems are built under impractical assumptions, such as homogeneous peer bandwidth and cooperative peers. In other words, every peer is assumed to have an equal and high bandwidth and to be cooperative in contribution of high upload bandwidth ranging from 200 Kbps to 2Mbps [2, 8]. These assumptions are not applicable in the real environment, where a number of peers are highly probable not to be cooperative. Even though peers are willing to contribute their bandwidth, the upstream bandwidth might be very limited if they are on ADSL or PSTN.

Some work has proposed incentive mechanisms to encourage peers to contribute their upstream bandwidth for handling free rider phenomenon. A well-known example in P2P file sharing is *tit-for-tat* mechanism that is used by BitTorrent [9-11], which was modified to apply to video streaming [12]. In [12], a peer's incentive is measured according to how much useful bandwidth it contributes back to the P2P system, and then determines its download rate. Wallach and Druschel applied the incentive mechanism on video streaming by frequently rebuild multicast tree to refuse to serve selfish peers [13]. It also introduced a debt mechanism which works as follow: when node *A* forwards a streaming data packet to node *B*, both nodes keep track that *B* owes *A* one packet. If the debt exceeds some threshold, *A* might refuse to send further data to *B*. In a *payment-based incentive mechanism*, peers earn points by forwarding data to others and then use these points to compete with each other for good parents, i.e., data suppliers [14]. It also introduces a bidding strategies which is designed to maximize peer own utility. A mechanism is provided for off-session peers to continue to make contributions by rewarding those points for future services.

In the previous work, since P2P systems limit peers' download rate based on their contribution, peers with small contribution are likely to suffer from frequent jitters on screen and longer buffering time. This penalty to selfish peers is too rough not to enable to predict the effect on the quality of service (QoS) experienced by the peers. The QoS degradation may be too severe when the download rate goes down below the video bitrate. Therefore, it is desirable to manage the QoS such as to provide different QoS for each client based on how much it cooperates for the P2P network.

The problem can be solved by managing a video quality. In other words, cooperative peers can play high quality video, and selfish peers can play low quality video. In this paper, we propose a P2P streaming system that encourages peers to contribute their upstream bandwidth by maintaining fairness among peers and providing different video quality between cooperative peers and selfish peers with a manageable way. Our proposed system determines if peers are cooperative or selfish by a rating mechanism based on their contributed upstream bandwidth, and offers a high quality video to cooperative peers as an incentive. Also we propose a tree reconstruction algorithm to make the system work effectively. The quality incentive is achieved by using multi-layer coding [15], which provides two levels of video quality with single stream. We adopt a *mesh-based architecture* [16] as our base P2P architecture, where sibling peers in tree exchange data segments. And, the effectiveness of the proposed system is demonstrated through simulation.

2. Related Work

For a P2P network to be operated actively and effectively, peers' contribution is necessary. However, a peer naturally tends toward selfishness on contributing its resource such as network bandwidth and CPU time. Some incentive mechanisms have been proposed to encourage peers to contribute their upstream bandwidth for handling the free rider phenomenon. A well-known incentive mechanism in P2P file sharing is *tit-for-tat* that is used by BitTorrent [9-11]. A file is divided into multiple segments, which are distributed at random. The peers requesting the file receive different segments, and then exchange their segments with other peers to get a complete file. Hence, a peer who provides much upload bandwidth to others would get much segments, that is, it is provided with much download bandwidth.

The tit-for-tat mechanism was modified to be applied to video streaming over P2P network [12, 17]. In the work, a peer's incentive is measured based on how much *useful* bandwidth it contributes back to the P2P system, and then the incentive determines how much download bitrate is provided to the peer. Unlike a file sharing, video streams have a timeliness property, where each data block has its deadline for playing back, because late blocks become obsolete. The useful bandwidth means the actual bandwidth that delivers blocks on time, not late blocks. Because continuous playback should be guaranteed in video streaming, tit-for-tat mechanism is applied into each chunk consisting of several segments, round by round, instead of a whole file.

Wallach and Druschel proposed an incentive mechanism for video streaming, which periodically rebuilds multicast tree to refuse to serve selfish peers [13]. If multicast trees are constructed randomly, a peer may be stuck if it is located on downstream from a selfish peer that is refusing to forward data to its children. By periodically reconstructing the multicast tree, a peer will only ever benefit or suffer from such situations for at most a fixed time period. The mechanism also introduces a debt maintenance that works as follows: when peer A forwards a stream data packet to a peer B, both peers can track that B owes A one packet. If the debt exceeds some threshold, A might refuse to send further data to B.

Tan and Jarvis proposed a payment-based incentive mechanism, where peers earn points by forwarding data to others and then use these points to compete with each other for good parents, i.e., data suppliers [14]. It also introduces a bidding strategy designed to maximize peer own utility, and provides a scheme for off-session peers to continue making contributions by rewarding points for future services.

Habib and Chuang introduced a rank-based peer-selection mechanism for a P2P media streaming system [18]. A peer's contribution is represented by a score, which is then mapped to the rank of this user among all users in the system. A peer with higher score has more flexibility in peer selection, while a free rider has limited flexibility in peer selection. The peers with higher score are expected to have better data supplier or parent.

Liu et al. proposed an incentive mechanism similar to our work, which suggested using layered video for incentives in P2P live streaming[19]. Although the objective and the approach are the same as our work, it is based on unstructured mesh architecture, where it is hard to control the exchange of the layers from a source. In the other hand, our work is divised on structured mesh architecture based on tree architecture, which is suitable to apply layered video as incentives.

3. Background

3.1 Multi-layer Video Coding

Domanski and Mackowiak devised a multi-layer video coder producing multi-layer frames for two levels of resolution for heterogeneous communication networks [15]. The coder is based on spatial-temporal scalability and data partitioning. Its goal is to achieve the aggregated bitrates of all layers encoded by the multi-layer coder possibly close to the bitrates of a video encoded with a single layer. The bitrate overhead measured relative to the single layer MPEG-2 bitstream varies about 10% - 25% for progressive television test sequences.

The coder consists of a low-resolution coder and high resolution coder. The bistreams produced by these two coders are split into some further layers by use of data partitioning. The low-resolution coder processes video sequences with reduced both spatial and temporal resolutions. Temporal resolution reduction is achieved by partitioning of the stream of B-frames: each second frame is not processed by the low-resolution coder. Therefore there exist two types of B-frames: BE-frames processed by the high-resolution coder only and BR-frames that are processed by both coders like I- and P-frames. An exemplary but typical *group of picture* (GOP) structure for a full-layer stream is as follows:

I-BE-BR-BE-P-BE-BR-BE-P-BE-BR-BE-P-BE-BR-BE.

Also a GOP structure for a base-layer stream is as follows:

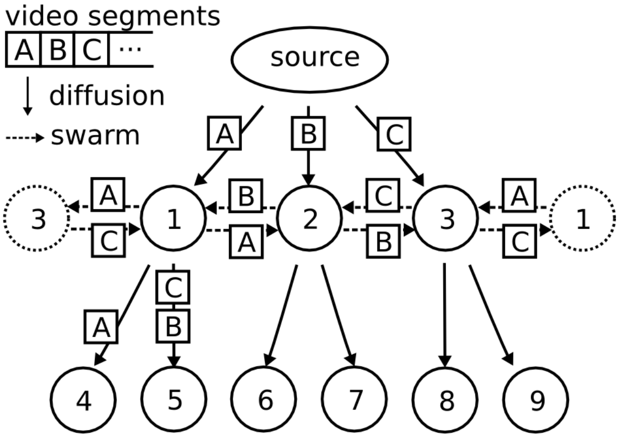
I-BR-P-BR-P-BR-P-BR.

3.2 Mesh-based Architecture

Mesh-based architecture was recently proposed as one of P2P streaming architecture [16]. It is the same as tree architecture except for that data can be delivered among the peers in the same level, not only from parents to children. In this architecture, participating peers form a mesh-based overlay and integrate a swarm-like content delivery. This approach is motivated by file-swarming mechanisms as in BitTorrent. File-swarming mechanisms distribute video segment among different peers which enables most peers to actively utilize their outgoing bandwidth.

In the mesh-based architecture, data segments of a video are distributed from a source in two phases: *diffusion* and *swarm*. In a diffusion phase, each video segment is delivered to a different subset of child peers periodically. Then, in a swarm phase, the mutually connected peers in the same level exchange or *swarm* their video segments until each peer has all video segments that the peers in the same level have. After that, each peer can start to play video. The time for one diffusion phase and swarm phase is considered as buffer time.

(Fig. 1) shows an example of mesh-based architecture with a source and nine peers. In the example, Peer 1, 2, and 3 are in the first level of the tree. The others are in the second level. The source has a complete video divided into segments: A, B, C, and so on. The segments are distributed through diffusion and swarm phases. The solid arrows indicate diffusion. The source diffuses segments to the peers in the first level. Each child peer receives a different segment: Peer 1 gets A, Peer 2 gets B and Peer 3 gets C. Then, in a swarm phase indicated as the dashed arrows indicate swarm, they exchange segment one another to obtain all the segments in the first level. Hence, Peer 1, 2, and 3 have all segments, i.e.,



(Fig. 1) Mesh-based architecture (some arrows and segments are omitted for clearance)

A, *B*, and *C*, and they can start to play the video. Hereby, the diffusion and swarm phases for the first level are over.

After the completion of the two phases in the first level, the peers in the level are ready to deliver their segments to the peers in the second level. As shown in the figure, Peer 1 diffuses segments to Peer 4 and 5. At the same time, Peer 1 also gets a new segment from the source, e.g., segment *D*. This process is repeated in each level of the mesh until all video segments are delivered to all peers.

4. Proposed System

In this section, we present a P2P streaming system that encourages peers to contribute their upstream bandwidth by maintaining fairness among peers and providing different video quality between cooperative peers and selfish peers with a manageable way. This section is organized with two parts: (i) a video quality incentive offering high quality video to cooperative peers, and (ii) a tree reconstruction mechanism making the system work effectively.

4.1 Incentive Mechanism

An incentive mechanism gives a reward to cooperative peers and a penalty to selfish peers, to encourage peers to contribute their upload bandwidth for P2P system. Therefore, each peer in Q-stream quantifies neighbor peers' cooperativeness based on their contributed upload bandwidth, and thereby allocates its upload bandwidth to them.

Specifically, each peer *i* keeps track of the download bandwidth, D_{ij}, provided by each neighbor peer *j* in the past swarm phases. Let D_{ij}^{new} be the download bandwidth from peer *j* to peer *i* in the last swarm phase and N_i be a set of neighbor peers that connected to peer *i*. D_{ij} is calculated by:

$$D_{ij} = (D_{ij} + D_{ij}^{new}) / 2 .$$

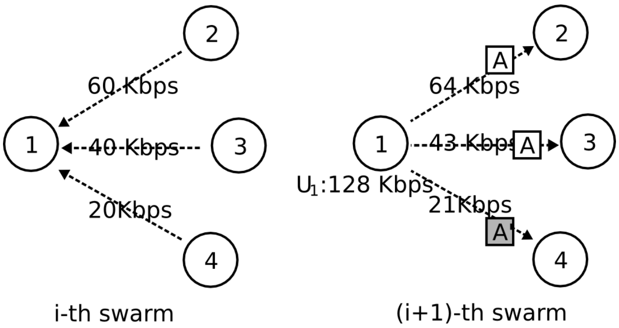
Then peer *i* calculates the upload bandwidth, U_{ij} allocated to each peer *j* in N_i as follows:

$$U_{ij} = (D_{ij} / D_i) \times U_i , \tag{1}$$

where $D_i = \sum_{j \in N_i} D_{ij}$ and U_i is the total upload bandwidth contributed by peer *i*. That is, U_{ij} is determined in proportion of the contribution of peer *j* to total download bandwidth provided to peer *i*. It is computed at the end of swarm phases, and allocated as the upload bandwidth for peer j for the next swarm phase. If D_{ij} relies only on the last swarm phase, it would be so sensitive, and if they rely on too many past swarm phases, it would be so insensitive. Hence, D_{ij} is determined such that the more recent information is reflected more in the calculation, that is, the effect of information in a swarm phase on the calculation decreases exponentially as time goes by.

(Fig. 2) shows an example, where peer 1 has a 128-Kbps upload bandwidth, and it has three neighbors, peer 2, 3, and 4. That is, U_i = 128 and N_i = {2,3,4}. In the last swarm phase, peer 1 took 60 Kbps, 40 Kbps, and 20 kbps from peer 2, 3, and 4, respectively. Assuming that the streaming begins from the last swarm, $D_{1,2}$=60, $D_{1,3}$=40, $D_{1,4}$=20, and D_1=120 (=60+40+20). Then, peer 1 computes the upload bandwidth allocated to each for according to Eq.(1): $U_{1,2}$ = 64 (=(60/120)·128), $U_{1,3}$ = 43 (=(40/120)·128), and $U_{1,4}$ = 21 (=(20/120)·128). That is, peer 1 allocates a bandwidth of 64 Kbps to peer 2, that of 43 Kbps to peer 3, and that of 21 Kbps to peer 4 for the next swarm phase.

The existing work does not take into account the video quality that the peers punished by the incentive mechanism would actually experience, but controls simply download bandwidth allocated to peers based on their cooperativeness. That approach is not suitable for video streaming application

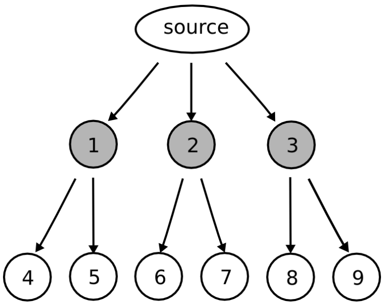


(Fig. 2) Bandwidth allocation and quality incentives that should manage the quality, because unmanaged quality degradation to selfish peers makes them leave the P2P network. Also, we cannot assume that multi-layered streams have been works in P2P without any consideration, because peers getting a low-quality stream cannot provide high-quality stream if they have enough upstream bandwidth. Hence, we have to devise an approach that have the selfish peers stay and become cooperative, instead of driving them out. The proposed system encourages peers to contribute their upstream bandwidth by maintaining fairness among peers and providing different video quality between cooperative peers and selfish peers with a manageable way.

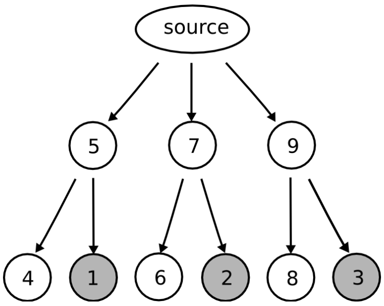
In our scheme, cooperative peers are received a good quality video as an incentive. Meanwhile, selfish peers experience quality degradation as a penalty. Peer i decides if it sends full segments to each neighbor or base segments by comparing U_{ij} with a threshold α_i that is determined as a bit rate of full quality video divided by the number of neighbor peers. If $U_{ij} \geq \alpha_i$, peer j would receive full quality video data, otherwise it would receive degraded quality video data. In the example of (Fig. 2), assuming the full bit rate is 128 Kbps, α_1 =43 (=128/3) Kbps. Thus, peer 1 transfers full segments to peer 2 and 3 because both $U_{1,2}$ and $U_{1,3}$ are greater than or equal to α_1, and base segments to peer 4 because $U_{1,4}$ is less than α_1 as illustrated in the figure. A' indicates the base segment of A.

4.2 Tree Reconstruction

In this subsection, we address a tree reconstruction to make our incentive mechanism work more effectively. Tree is reconstructed regularly every end of swarm phase and also irregularly when a peer leaves the tree. At the beginning of video streaming, the tree structure is created in the order of arrival because there is no information about how much bandwidth is contributed by each peer. Thus, peers who join the stream first would get good positions near the source. In (Fig. 3(a)), selfish peers dominate the upper levels of tree and cooperative peers are located in the lower levels. The diffusion phase might be failed since the selfish peers are likely not to provide enough upload bandwidth to their child peers. Even if the diffusion is successful, it is highly probable that the selfish peers have only base segments and accordingly their descendants get only base segments regardless of the cooperativeness. With this kind of tree structure, our incentive mechanism would not work. That is why we devised a mechanism promoting cooperative peers up to the top so as to reconstruct this bad structure to a good one like (Fig. 3(b)), in order to minimize the ripple effect from the selfishness.



(a) Before



(b) After

(Fig. 3) Peer promotion (the shaded circles indicate selfish peers)

The promotion mechanism moves cooperative peers up and selfish peers down by replacing the selfish parents with the cooperative children. It is applied for each level from the highest level to the lowest level of the tree. The promotion method is initiated by the source, and each peer keeps its actually contributed upload bandwidth reported by its neighbors at the end of each swarm phase. If peer i contribute such small bandwidth that it can send only base segments to its children, the source finds a peer who contribute higher upload bandwidth among the children of peer i. Then, the source activates the promotion method involving peer i, the parent of peer i, and the elected peer from the children of peer i. Let peer p_i be the parent of peer i and peer c_i be the elected child. The promotion method replaces peer i with peer c_i by changing information in peer i, peer p_i, peer c_i, and other neighbors of peer i and c_i. To swap peer i and c_i, peer p_i replaces peer i with peer c_i in its children set and peer c_i replaces its children with those of peer i and announces its joining to the neighbors of peer i. And then peer c_i registers peer i as its child and peer i replaces its children with the children of peer c_i and announces its join to the past neighbors of peer c_i. This procedure should be atomic for continuous streaming.

5. Performance Evaluation

5.1 Simulation Setup

We demonstrate our incentive mechanism and tree reconstruction mechanism by simulation. We implemented the simulator program in Java. In the simulation, a video bitrate is set to 128 Kbps, and the total number of peers is 2,000. <Table 1> shows the upload bandwidth distribution of the peers. And, a peer has nine neighbors for swarm phases. The performance metrics in our simulation are the following:

- Distance(i): level of peer i on the tree.
- Quality(i): ratio of the number of full segments to total number of segments received by peer i.
- DB(i): download bandwidth provided to peer i.
- Fairness(i): (upload bandwidth contributed by peer i) / (download bandwidth provided to peer i).

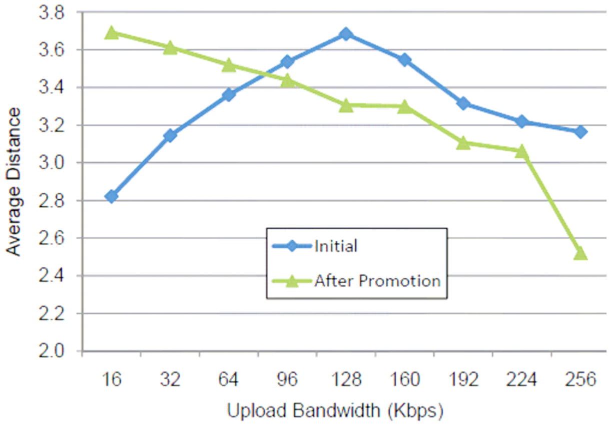
The ultimate objective of an incentive mechanism is to maximize the capacity of a P2P system by encouraging peers to contribute their bandwidth. Unfortunately, it is impossible to anticipate how each peer reacts on the incentive mechanism. Hence, we cannot measure the performance metric and each incentive mechanism has its own philosophy and characteristics. That is why there is no comparison with existing mechanisms in our experiments.

〈Table 1〉 Upload bandwidth distribution

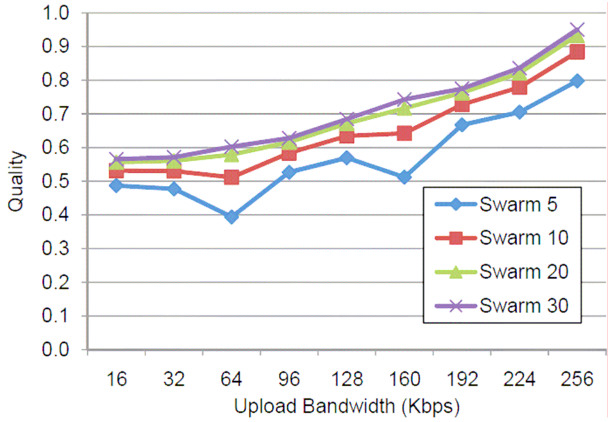
BW (Kbps)	16	32	64	96	128	160	192	224	256
# of peers	140	160	200	300	400	300	200	160	140

5.2 Experimental Results

The tree reconstruction is needed to fix a bad structure, where selfish peers are placed in higher levels so that peers in lower levels cannot be reliably served with a full quality. Thus, we suggested a promotion mechanism in Section 4.2. (Fig. 4) shows average distance from the root, for each peer class of upload bandwidth. In the initial tree, the peers of 16 and 32 Kbps are placed near to the root and the cooperative peers of 128 and 160 Kbps are placed relatively far. That is the initial tree is not efficient for video streaming and not effective for applying our incentive mechanism. After applying the promotion mechanism, we can see that the distance of more cooperative peers is shorter. In other words, the peers who contribute more upload bandwidth are placed nearer to the source as the result of our promotion mechanism.



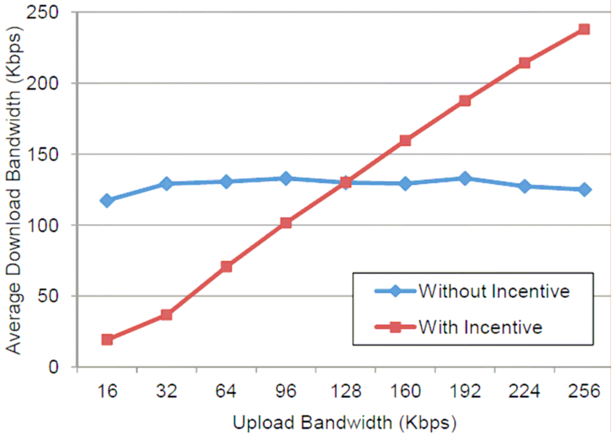
(Fig. 4) Peer promotion (the shaded circles indicate selfish p[eers)



(Fig. 5) Average Video Quality

In our proposed system, full quality video is provided to cooperative peers, and base quality video is provided to selfish peers. To demonstrate the effectiveness of our incentive mechanism, we measured the proportion of full segments to total segments received by each peer, which is defined as video quality in our experiments. (Fig. 5) shows the average video quality for each peer class of upload bandwidth, at the end of the 5th, 10th, 20th, and 30th swarm phases. Though the video quality values in the initial states are not consistent, they converge to an expected result as time goes by – the peers contributing more upload bandwidth get high video quality. In the figure, the most selfish peers with 16 and 32 Kbps got the video quality of lower than 0.6, but the most cooperative peers with 224 and 256 Kbps got that of higher than 0.8.

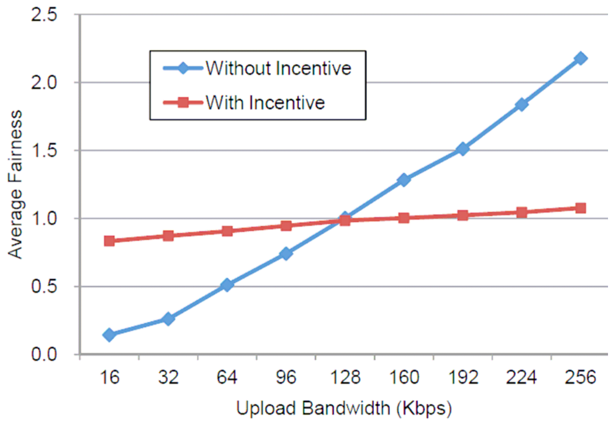
The objective of an incentive mechanism is to provide more download bandwidth to cooperative peers and less bandwidth to selfish peers. Thus, we measured the download bandwidth that each peer actually received. (Figure 6) shows the average download bandwidth for each peer class of upload bandwidth. Without our incentive mechanism, average



(Fig. 6) Average Download Bandwidth

bandwidths actually received to all peer classes are almost even. With our incentive mechanism, however, the bandwidth increases linearly as upload bandwidth goes high.

It is reasonable to provide download bandwidth to each peer as much as it contributes its upload bandwidth to P2P network. Thus, we define a fairness of a peer as a proportion of upload bandwidth actually contributed to download bandwidth actually received by the peer. That fairness is greater than one means that the peer gives more bandwidth than it obtains (Fig. 7) shows the average fairness for each peer class of upload bandwidth. Without our incentive mechanism, the P2P system is so unfair because all peers receive similar download bandwidth regardless of their bandwidth contribution. That is why the fairness values increase as upload bandwidth goes high in the figure. With our mechanism, the values are distributed close to one. That is, each peer tends to receive bandwidth as much as it contributes.



(Fig.7) Average Fairness

6. Conclusion and Future Work

In this paper, we proposed a P2P streaming system that encourages peers to contribute their upstream bandwidth by maintaining fairness among peers and providing different video quality between cooperative peers and selfish peers with a manageable way. Our proposed system determines if peers are cooperative or selfish by a rating mechanism based on their contributed upstream bandwidth, and offers a high quality video to cooperative peers as an incentive. Also we propose a tree reconstruction algorithm to make the system work effectively. Through simulation, we showed that the tree reconstruction algorithm worked effectively, and our incentive mechanism allocated more download bandwidth to cooperative peers and punished selfish peers with low quality video.

As a future work, we are planning to extend this work by giving streaming reliability as an incentive. In P2P streaming, a disconnection is a frequent and serious problem due to peer leaving.

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