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Abstract

Although peer-to-peer networks are more scalable than client-server ones, they face efficiency challenges. One of them is the selfish behavior of non-cooperative peers. Another challenge is the short time peers stay connected to the system, which causes disruptions of the delivery of time-constrained content. This paper introduces an incentive mechanism to address both problems in peer-to-peer networks with live streaming.

1 Introduction

Peer-to-peer networks have been considered for the delivery of video streaming, either replacing or complementing the client-server architecture. In networks with live streaming, the content is delivered synchronously among peers, typically by using multicast distribution trees, whereas in networks with on demand streaming the content is delivered asynchronously [1, 2]. In the latter, it is possible that different peers serve different segments of the same streaming for a given request.

However, the behavior of non-cooperative peers, who cooperate less than consume, is a true challenge to the effectiveness of video delivery services. Previous research on peer-to-peer file sharing pointed out that at most 30% altruistic peers serve the majority of all requests [3], which is considered not sufficient for the delivery of real-time content [4].

Moreover, peers staying connected to the system for short periods can cause disruptions of video delivery. Several peers can be affected by the disconnection of an outgoing peer as a consequence of his/her position in the multicast trees. Hence, peer-to-peer networks with live streaming call for incentive mechanisms to stimulate peers to cooperate as well as to stay connected longer.

In this paper, we propose a novel incentive mechanism for peer-to-peer networks with live media streaming in order to increase cooperation among peers as well as to enlarge their session durations.

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The aim is to increase scalability and the stream quality as well as to decrease the number of disruptions. In line with that, the following questions are answered along the paper: (1) what is the percentage of cooperative peers necessary to provide an acceptable quality of service? (2) how much should peers cooperate to have a scalable system? (3) is it worthy to increase session durations to reduce disruptions in multicast trees?

The remaining of this paper is organized as follows. In Section 2, the CoopNet system, used as an example of peer-to-peer networks with live streaming, is described. In Section 3, a new incentive mechanism is introduced. In Section 4, simulation experiments are described and in Section 5 the mechanism is evaluated. Related work is presented in Section 6 and some conclusions are drawn in Section 7.

2 The CoopNet System

CoopNet [5] is a peer-to-peer network with live media streaming conceived to ameliorate the scalability constraint of the client-server architecture. The CoopNet system supports peer heterogeneity and takes into consideration network congestion [6]. As an enhancement to the original design, which employed multiple descriptions coding (MDC), layered multiple description coding (LMDC) [7] was introduced for adapting the stream quality to different network scenarios. Peers with bandwidth constraint receive only the descriptions of the base layers, while peers with less stringent constraints receive in addition the descriptions of other layers.

CoopNet employs multiple distribution trees. Each peer is admitted as an interior node in just one tree and as a leaf node in the remaining $n-1$ trees. In this way, path diversity is increased and, consequently, the system becomes more fault tolerant. Furthermore, in case a peer is a leaf node in all trees, his/her outgoing bandwidth cannot be utilized for cooperation.

Peers may receive and forward a different number of descriptions. Their incoming (consumption) bandwidth is determined by the number of distribution trees in which they are admitted, whereas their outgoing (cooperation) bandwidth is determined by the number of own children admitted in the tree on which the peers are interior nodes. The higher the number of descriptions received, the lower the distortion of the reconstructed signal is [5, 7].

To cope with congestion, a bandwidth adaptation protocol was adopted [6]. In this protocol, parent and child nodes act together to infer the location of congestion.

3 A Novel Incentive Mechanism

It is our best knowledge that no incentive mechanism has been proposed to CoopNet. According to [8], barter trade is the most suitable incentive pattern for synchronous delivery such as the one in peer-to-peer networks with live streaming, since peers cooperate while connected to the system. Under this pattern, peers trade their outgoing bandwidth in order to receive a given incoming bandwidth, which represents a desired stream quality. The required outgoing bandwidth for a given incoming bandwidth can vary according to the cooperation tax. Compared to other incentive patterns, barter trade has desirable characteristics such as anonymity, persistence, scalability and localization.

The mechanism proposed in this paper involves the barter trade pattern as a primary incentive mechanism to increase cooperation. By increasing the total available bandwidth, enhanced stream quality is obtained, since the distribution trees can admit a greater number of nodes.

In order to motivate peers to stay connected for long periods, remuneration should be offered to them. Barter trade already offers a stream quality proportional to the peer's cooperation. One possible choice for remuneration could be to decrease the cooperation taxes imposed by the barter trade pattern for those peers who stay connected longer. Nonetheless, this approach produces resource deficit. To compensate such deficit, the cooperation taxes for peers who have been connected for a short period of time should be increased.

For the enlargement of the connection period, a reputation mechanism was adopted as a secondary incentive mechanism. This mechanism modifies the cooperation taxes of the barter trade pattern according to the session durations. Peers' reputations are proportional to the duration they stay connected and their cooperation taxes are inversely proportional to their reputations. The aim of this secondary incentive is to decrease tree disruptions by motivating peers to stay connected longer.

Let R_i be the reputation of the i^{th} peer and R_s the reputation of the video servers, which are always connected to the system, thus, $0 \leq R_i \leq R_s = 1$. Let B_{Oi} be the outgoing bandwidth of the i^{th} peer for cooperation; B_{Ii} the incoming bandwidth of the i^{th} peer used to receive the stream with the desired quality; and CR_i the cooperation ratio of the i^{th} peer, which represents the cooperation tax considered by the barter trade pattern. The relationship between the consumed and the cooperated bandwidths can be expressed as:

$$B_{Oi} = CR_i.B_{Ii} \tag{1}$$

By using the primary incentive mechanism, this relationship is enforced to all peers, i.e., no peer can consume more bandwidth than the bandwidth granted and no peer needs to cooperate more than the necessary, which is determined by the desired stream quality. To implement the secondary incentive mechanism, the cooperation ratio of each peer should vary according to their reputation.

For recently connected peers, $R_i = 0$ and CR_i reaches its maximum value, since for a given incoming bandwidth the cooperation tax for these peers achieves its maximum value. As the connection periods of these peers increase but stay shorter than a certain time threshold, R_i and CR_i are determined proportionally to session durations. When connection periods are longer than such time period, $R_i = R_s = 1$, CR_i reaches its minimum value and both parameters do not vary anymore for these peers, since the cooperation taxes for a given incoming bandwidth reaches the lowest possible value. These peers are then considered "steady cooperators" and "pay" the least for their desired consumption.

Let RT be the required time for a peer to become a steady cooperator, i.e., the time period in which R_i and CR_i still varies for that peer. Such parameter was introduced so that peers with long session durations do not excessively diminish the reputations of recently admitted peers. Without the employment of this parameter, the proportion of peers with cooperation ratios greater than 1 and the proportion of peers with cooperation ratios less than 1 become unevenly balanced, causing either excess or lack of bandwidth in the system. By using the parameter RT, such unbalancing is avoided, since clients with session durations longer than this threshold (steady cooperators) are not considered anymore for the determination of other peers' reputation.

While the connection period of the i^{th} peer is shorter than RT, the R_i value is determined proportionally to the connection period of the oldest peer in the system who has not yet become a steady cooperator. Let t_* be the connection period of such peer and t_i the connection period of the i^{th} peer. The reputation of the i^{th} peer is calculated as:

$$R_i = t_i/(t_* + 1) \quad (2)$$

Note that R_i is equal to R_s only after $t_i \geq RT$. Let LB_{CR} and UB_{CR} be the lower and upper bounds of the cooperation ratios used by the system, respectively. The cooperation ratio of the i^{th} peer is computed as:

$$CR_i = UB_{CR} - R_i(UB_{CR} - LB_{CR}) \quad (3)$$

The new incentive mechanism is composed by the primary and secondary incentive schemes described before. Figure 1 presents the algorithm for balancing B_{Ii} and B_{Oi}, based upon CR_i, and Figure 2 presents the algorithm to determine the values of R_i, CR_i, t_i and t_*. The values of the parameters LB_{CR}, UB_{CR} and RT need to be determined so that the new incentive mechanism can operate properly, which will be discussed in Section 4.

Computation of B_{Ii} and B_{Oi}

Determine(B_{Ii}, B_{Oi})
Begin
    While the i^{th} peer is connected,
        Use $B_{Oi}(= CR_i.B_{Ii})$ of his/her outgoing
        bandwidth for descriptions forwarding;
    If the i^{th} peer offers $B_{Oi} < CR_i.B_{Ii}$,
    Then
        Decrease the quality of their incoming
        stream to $B_{Ii} = B_{Oi}/CR_i$;
End.

Figure 1: Computation of B_{Ii} and B_{Oi} values (primary incentive).

A novel bandwidth adaptation protocol was defined so that the incentive mechanism can be integrated to the CoopNet architecture. It operates as follows:

- It drops incoming traffic when either there is congestion in the incoming link *or* $B_{Oi} < CR_i.B_{Ii}$;
- It drops outgoing traffic when either there is congestion in the outgoing link *or* $B_{Oi} > CR_i.B_{Ii}$;
- It adds incoming traffic whenever no congestion exists in the incoming link for a certain period of time *and* $B_{Oi} > CR_i.B_{Ii}$;
- It adds outgoing traffic whenever no congestion exists in the outgoing link for a certain period of time *and* $B_{Oi} < CR_i.B_{Ii}$.

Computation of R_i, CR_i, t_i and t_*

Determine(R_i, CR_i, t_i, t_*)
Begin
    If the i^{th} peer has just connected, then
        $R_i \leftarrow 0$;
        $CR_i \leftarrow UB_{CR}$;
        $t_i \leftarrow 0$;
        Update(t_*);
    If the i^{th} peer is already connected, then
        If $t_i \geq RT$, then
            $R_i \leftarrow R_s$;
            $CR_i \leftarrow LB_{CR}$;
            Update(t_*);
        Else
            $R_i \leftarrow t_i/(t_* + 1)$;
            $CR_i \leftarrow UB_{CR} - R_i(UB_{CR} - LB_{CR})$;
    If the i^{th} peer has disconnected, then
        Update(t_*);
End.

Figure 2: Computation of R_i, CR_i, t_i and t_* values (secondary incentive).

The i^{th} peer can choose either the desired stream quality or his/her outgoing bandwidth available for cooperation.

The algorithms presented in Figures 1 and 2 are executed periodically at the server for determining for each peer the solution of the inequalities described before. As the server is already involved in all traffic dropping and adding for the bandwidth adaptation protocol, the implementation the algorithm is quite simple.

4 Simulation Experiments

A simulator for peer-to-peer networks with live streaming was developed. It is our best knowledge that none of the existent simulators implement synchronized content distribution in peer-to-peer networks. The architecture with multiple distribution trees and LMDC, described in [5, 6], was implemented. The deterministic tree construction algorithm in [5, 6] was implemented as well as the new bandwidth adaptation protocol described in Section 3. The total bandwidth of the stream, the number of distribution trees and the link congestion probability were, respectively, 128 Kbps, 16 and $P = 0.1$ [5, 6].

A non-stationary process consisting of sequences of piece-wise-stationary Poisson arrival processes, each lasting for 15 minutes [9], with rate varying between 5 and 20 arrivals per minute [10] was used to model the arrival of new peers. For modeling flash crowds, a Poisson arrival process with a fixed arrival rate of 80 arrivals per second [5] was employed.

Session duration follows a lognormal distribution with parameters $\mu = 5.74$ and $\sigma = 2.01$ [9]. The same distribution was employed for the extra time peers stay connected due to the employment of the secondary incentive mechanism.

To simulate an heterogeneous environment, connection classes with their own incoming and outgoing bandwidth were created, defined according to the statistics of Brazilian Internet access providers [11]; they are: Dial-up, ADSL 150 Kbps, ADSL 350 Kbps, ADSL 600 Kbps, ADSL 1 Mbps, HFC 150 Kbps, HFC 300 Kbps, HFC 600 Kbps and HFC 1200 Kbps. Dial-up peers never stay connected longer.

The following metrics were collected in the simulations:

- *Stream quality*: the mean number of descriptions received by the peers during their session durations;
- *Admission capacity*: the mean number of peers the system can admit in all distribution trees;
- *Blocking probability*: the probability that a new peer is not admitted in any distribution tree;
- *Mean tree disruption rate*: the mean number of tree disruptions per second experienced by the peers during their session durations.

Setting the Values of LB_{CR}, UB_{CR} and RT

The lower (LB_{CR}) and the upper (UB_{CR}) bounds for the cooperation ratio as well as the threshold for the duration of a peer to be considered a steady cooperator (RT) are values which demand knowledge of an operating network. Procedures for dynamically setting these values should be derived if the proposed mechanism is adopted in an operating network. By now, these values are determined via simulation for the network scenarios considered.

The values of LB_{CR}, UB_{CR} and RT should yield to the maximum stream quality. The maximum quality is achieved for a cooperation ratio equal to 1. Besides that, any combination of LB_{CR} and UB_{CR} values giving an arithmetic mean 1 produces high quality of reception. Finally, RT values which balance the proportion of peers with cooperation ratios greater than 1 and the proportion of peers with cooperation ratios less than 1 also produce high quality of reception. This optimum value of the cooperation ratio is quite intuitive since it balances the supply and the demand of bandwidth. With ratios less than 1, the supply for cooperated bandwidth is less than the respective demand, which means that peers consume more than they cooperate. In this case, the system does not have enough resources to serve all requests and, hence, peers are admitted in less trees than their incoming bandwidths would allow, lowering the stream quality. With ratios greater than 1, the supply is higher than the demand. However, in spite of the excess resources in the system, peers most of the time do not receive the number of descriptions which their incoming bandwidth would allow because they do not have enough outgoing bandwidths to "pay" the requested cooperation tax, i.e., the system charges peers more than the necessary in terms of cooperation.

In order to evaluate the new incentive mechanism, two scenarios were created: *24h* and *5mFC*. In the former, the system is under normal traffic (without flash crowd) for twenty four hours. In the latter, the system is under intense flash crowd load for five minutes.

5 Evaluation of the Mechanism

In this section, the benefits of both primary and secondary incentive mechanisms are investigated. A comparative analysis of the system with (1) no incentive mechanism, (2) only the primary incentive and (3) both the primary and the secondary incentives was conducted. These three scenarios correspond, respectively, to the first, second and third groups in Table 1. In the first group, the number of cooperative peers was varied, from 0% (only the server admits) to 100% (complete altruism environment). In the second group, 100% of the peers cooperate, due to the employment of barter trade, and the cooperation ratio was varied, from 0.3 (cooperated bandwidth equal to 30% consumed bandwidth) to 2 (cooperated bandwidth equal to 200% consumed bandwidth). In the third group, clients' cooperation ratios are different amongst them and calculated according to the parameters LB_{CR}, UB_{CR} and RT, set as it was described in the previous section. RT values are provided in seconds.

First Group			**Third Group**				
e	Inc.	Coop.	e	Inc.	LB_{CR}	UB_{CR}	RT (s)
1	None	0%	15	Rep.	0.5	1.5	16415
2	None	10%	16	Rep.	0.6	1.4	14070
3	None	25%	17	Rep.	0.7	1.3	11725
4	None	30%	18	Rep.	0.8	1.2	9380
5	None	50%	19	Rep.	0.9	1.1	7035
6	None	75%	20	Rep.	0.95	1.05	4690
7	None	100%	21	Rep.	1	1	2345
Second Group			22	Rep.	1	1.05	2345
e	Inc.	CR	23	Rep.	1	1.1	2345
8	B.T.	0.3	24	Rep.	1	1.2	2345
9	B.T.	0.5	25	Rep.	1	1.3	2345
10	B.T.	0.75	26	Rep.	1	1.4	2345
11	B.T.	1	27	Rep.	1	1.5	2345
12	B.T.	1.25					
13	B.T.	1.5					
14	B.T.	2					

Table 1: Parameter variation in the scenarios *24h* and *5mFC*.

5.1 Efficiency of the Primary Incentive Mechanism

The horizontal axes in all graphics presented in this paper identify the experiments in Table 1. Figures 3 and 4 show the stream quality for the experiments of the scenarios *24h* and *5mFC*, respectively. It can be noticed, in the first group of experiments (no incentive, from 1 to 7), that the percentage of cooperative peers suggested in the literature (30%) is not sufficient to provide a satisfactory quality of reception. It provides only 6 descriptions out of 16. In order to obtain a stream quality at least half of the maximum, it would be necessary that 50% of the peers cooperate. If 100% of the peers cooperate with their full bandwidth, a stream with quality of 15 descriptions (experiment 7) would be obtained. When no peer cooperate (experiment 1), the system degenerate to a client-server architecture, with a stream quality of roughly 2 descriptions.

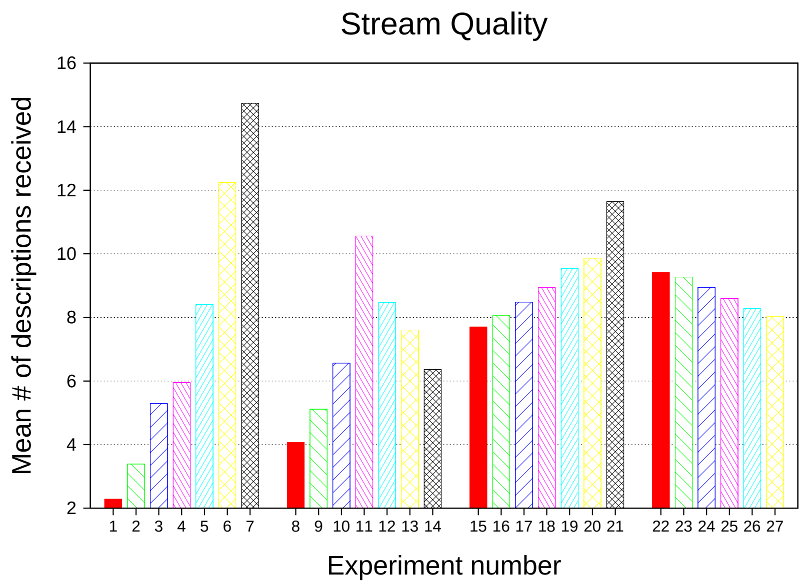

Figure 3: Stream quality for each experiment of the scenario *24h*.

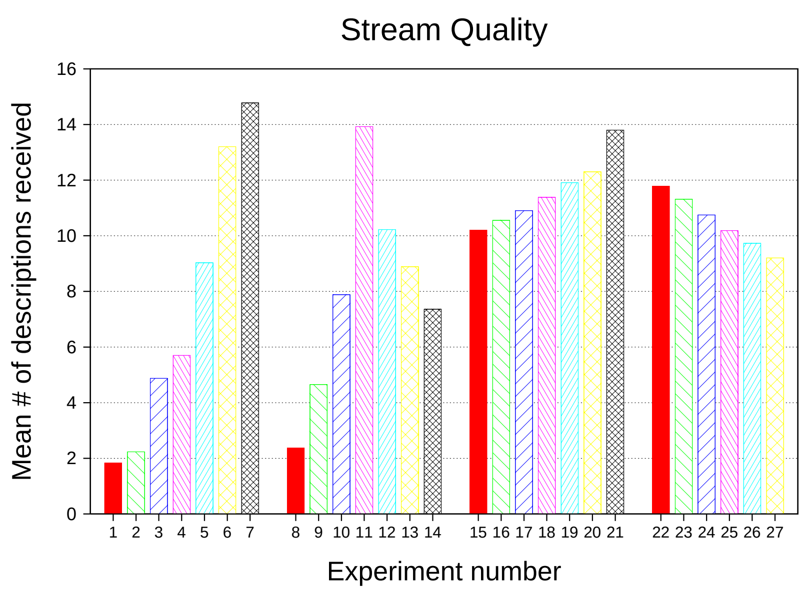

Figure 4: Stream quality for each experiment of the scenario *5mFC*.

It can be seen, in the second group of experiments (only barter trade, from 8 to 14), that the cooperation ratio value which maximizes the stream quality is 1, confirming previous discussion. Besides that, the stream quality obtained by using only the primary incentive with cooperation ratio 1 (experiment 11) is about 11 for the scenario *24h* and almost 14 for the scenario *5mFC*. This means an improvement in quality of almost the double for the scenario *24h* and more than the double for the scenario *5mFC*, compared to the case with 30% of the peers cooperating with no incentive mechanism (experiment 4).

It can be noticed, in the third group of experiments (with reputation, from 15 to 27), that the larger is the variation of the cooperation ratio, the lower is the stream quality obtained by peers, which results from the overhead of the new incentive mechanism. The quality difference between the case with the largest difference between the bounds (experiment 15) and the case with no variation (experiment 21) is 4 descriptions. Even for a small variation of 0.05 (experiments 20 and 22), the stream quality drops 2 descriptions. Therefore, the width between the lower and the upper bounds impacts 2 to 4 descriptions on the stream quality.

Figures 5 and 6 display the blocking probability for the scenarios *24h* and *5mFC*, respectively. The main observation is that all peers are admitted in the second and in the third groups (experiments from 8 to 27), differently from what happens in the first group (experiments from 1 to 7). Taking into account that the arrival rate was high in the scenario *5mFC* (flash crowd), the absence of blocking in these two groups is a clear evidence that the new incentive mechanism increases the system scalability. In the first group, there is no blocking only in the experiments in which more than 50% of the peers cooperate (experiments 6 and 7); situations that do not correspond to the collaboration pattern in current peer-to-peer systems [3]. When blocking occurs, in the first group (experiments from 1 to 5), the blocking probability is 10 times greater in the scenario *5mFC* than it is in the scenario *24h*.

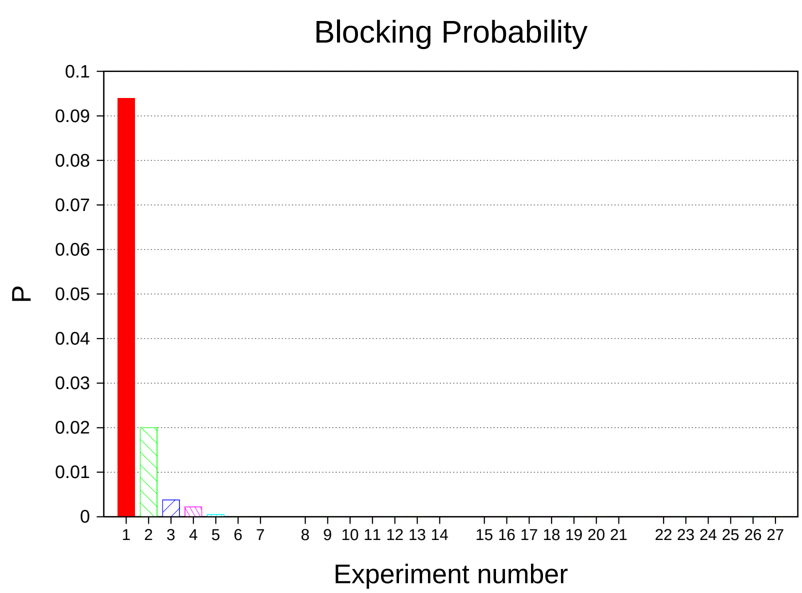

Figure 5: Blocking probability for each experiment of the scenario *24h*.

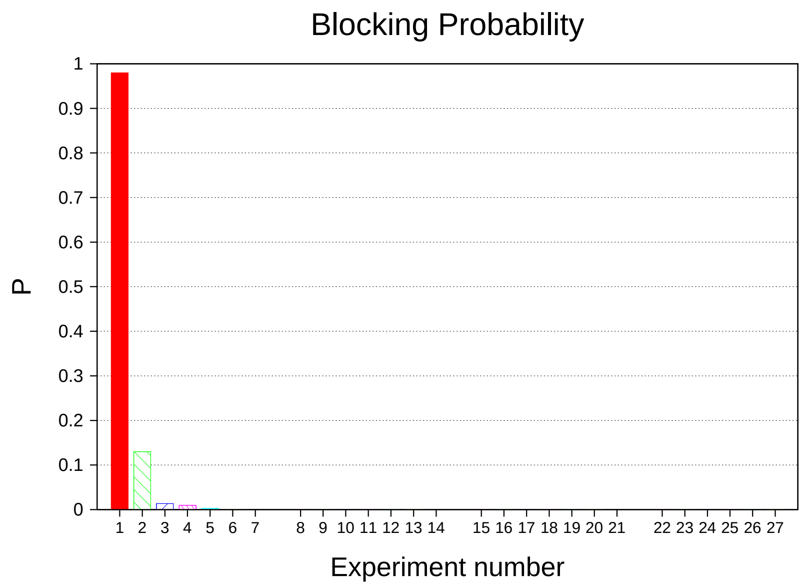

Figure 6: Blocking probability for each experiment of the scenario *5mFC*.

When comparing experiment 4 (30% of the peers cooperating with 100% outgoing bandwidth) with experiment 8 (100% of the peers cooperating with 30% incoming bandwidth), it can be noticed that although the stream quality in experiment 8 is lower than the one in experiment 4, a higher number of peers is accepted in experiment 8. This finding is in conformance with the observation that low cooperation ratios (30%) make unfeasible most of peer-to-peer systems, specially the ones with time-sensitive content distribution [4].

Figures 7 and 8 show the system admission capacity for the scenarios *24h* and *5mFC*, respectively. Analyzing experiments 15 to 21, in which the arithmetic mean of the lower and the upper bounds is 1, resources were used efficiently. In these experiments, not only is the stream quality good (Figures 3 and 4), but also there were available resources to admit peers in both scenarios *24h* and *5mFC*.

5.2 Efficiency of the Secondary Incentive Mechanism

Figures 9 and 10 show the tree disruption rates for the scenarios *24h* and *5mFC*, respectively. Under normal traffic (scenario *24h*), there is no significant improvement in the tree disruption rates when peers stay connected longer. Under flash crowds, a considerable reduction in the tree disruption rates can be noticed when session duration is long (experiments 15 to 27). By comparing experiments 11 and 21, there is a 45% difference in the tree disruption rates. Instead of 0.78 (1 disruption at each 1.28 seconds), there is 0.43 (1 disruption at each 2.32 seconds) disruptions. Besides that, by comparing the results obtained in experiment 21 to that other experiments in the third group (with reputation, from 15 to 27), the tree disruption rates are almost the same regardless the lower and the upper bounds adopted.

To clarify whether results obtained in the scenario *5mFC* could be biased by the short simulation

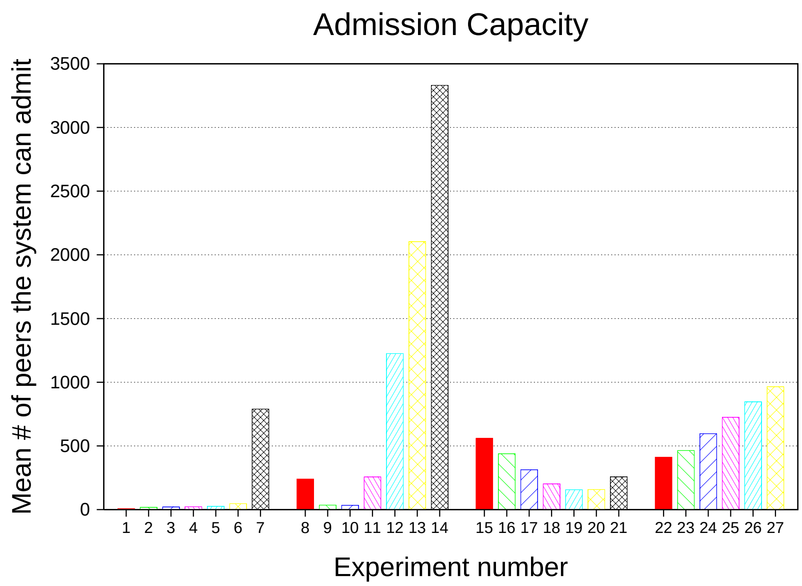

Figure 7: Admission capacity for each experiment of the scenario *24h*.

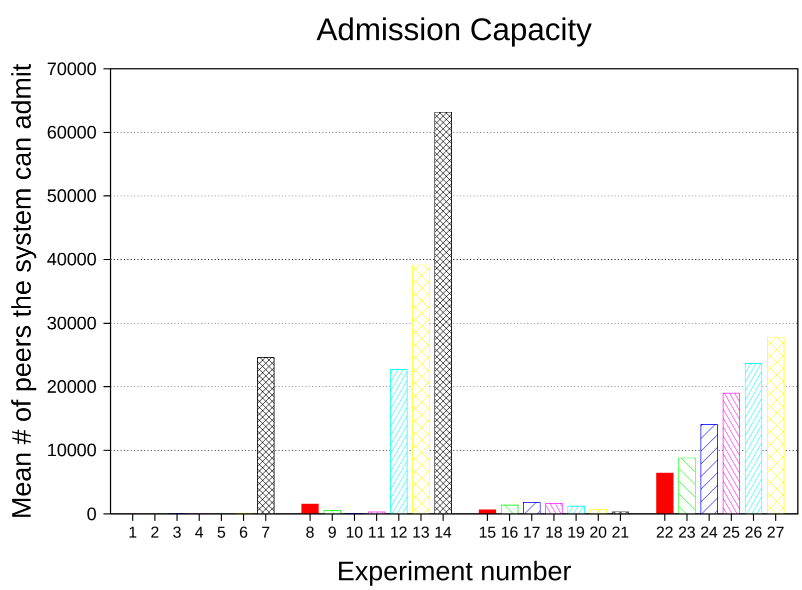

Figure 8: Admission capacity for each experiment of the scenario *5mFC*.

period, the arrival rate was kept constant and the simulation duration varied. The stream quality, system admission capacity and blocking probability were roughly the same as the ones observed in the scenario *5mFC*. Specially, the decrease of the tree disruption rates was also around 45%, showing that the tree disruption rates decreased only because of an increase in the arrival rate.

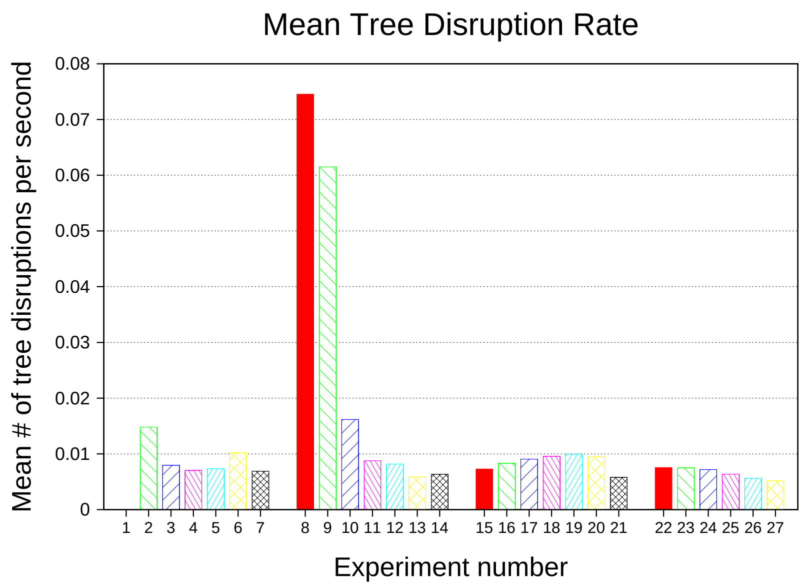

Figure 9: Mean tree disruption rate for each experiment of the scenario *24h*.

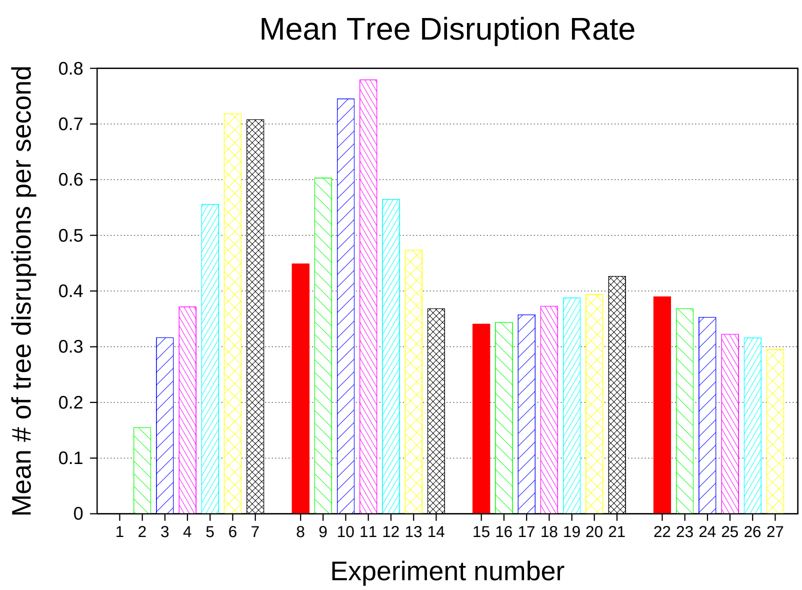

Figure 10: Mean tree disruption rate for each experiment of the scenario *5mFC*.

6 Related Work

In [12], an approach similar to ours was proposed. It takes advantage of the excess bandwidth to allow peers with restricted bandwidth to receive higher quality levels than the ones determined by their cooperation bandwidth. In the present work the excess bandwidth is used to allow peers who have stayed longer connected to cooperate less than those who have stayed during shorter periods, thus motivating longer session durations.

In [13], a reputation scheme is used for peers to remember freeloaders who refused to cooperate in the past, offering a chance to retaliate the offenders in the future. The work in [4] considers a reputation scheme based on percentile for the provisioning of differentiated service. Moreover, Bittorrent [14], which is one of the most popular peer-to-peer file sharing applications, uses the barter trade incentive pattern to stimulate cooperation.

7 Conclusion

In this paper, we proposed a new incentive mechanism for peer-to-peer networks with live streaming, aiming at increasing scalability and the stream quality as well as to decrease the number of tree disruptions. The three questions posed in the Introduction are now answered. Results indicate that a percentage of 30% of cooperative peers is not sufficient to provide even half of the "ideal quality". Besides that, blocking probability values show that some peers are not admitted even without flash crowd. Results indicate that a percentage of 50% cooperating peers provide acceptable quality.

By using the primary incentive mechanism, all peers start to cooperate and, as a consequence, the stream quality is increased. Comparing to system with no incentive mechanism, the number of received descriptions is almost the double, for scenarios without flash crowd, and it is more than the double, for scenarios with flash crowd. The primary incentive mechanism is essential to make it feasible the use of peer-to-peer networks for video on demand services. Moreover, peers should be charged exactly the same amount of bandwidth they consume, which balances the supply and the demand of resources in the system (cooperation ratios equal to 1).

The secondary incentive mechanism diminishes the stream quality in 2 to 4 descriptions out of 16. The utilization of the mechanism decreases the number of tree disruptions only in scenarios with flash crowd. In such cases, the number of disruptions decreased by 45%, compared to the scenarios with only the primary incentive mechanism. Results pointed out that it is worthy to increase session durations only when the arrival rates are reasonably high so that the benefits compensate the cost of the mechanism. Besides that, the secondary incentive mechanism could be used to increase revenue from advertises.

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