P2P Incentive Model for QoS based Streaming Systems

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Abstract—P2P streaming today is one of the most challenging techniques to deliver real-time streaming on the Internet. Incentive mechanisms take a crucial part of the P2P algorithms in order to avoid uncooperative and eliminate malicious behavior. In this paper we present a monetary incentive mechanism based on the taxation incentive schemes. We use a model of a P2P streaming service to apply the idea and validate the quantitative effect on both the users’ and the provider’s welfare in the system. A billing model based on QoS levels for the perceived video that offers a remuneration incentive for the cooperative users, contributes to the P2P streaming because of the two main reasons: increases provider’s welfare in terms of monetary benefit and saves infrastructure cost; increases users’ welfare in terms of increased cooperation and motivation to participate in the streaming.

Index Terms—incentive, P2P, streaming, remuneration, multimedia, billing

I. INTRODUCTION

Nowadays, multimedia streaming is becoming one of the most popular Internet applications. We are getting used to follow live events directly from a website or to watch selected contents on-demand from anywhere around the world with the click of a button. These solutions are mainly based on two different architectures: peer-to-peer (P2P) or centralized. Each has its own advantages both in technical and economical terms for content providers, distributors and final users.

Although widely accepted and increasingly used, P2P faces an important challenge: preventing abusive and uncooperative users from joining the overlay. Several P2P applications still fail to detect such behavior. Furthermore, as highly dynamic process, P2P streaming suffers of instability due to peer churn, since the users can join and leave the network voluntarily. This limits the exploitation of P2P for commercial multimedia streaming applications on the Internet.

In this paper we describe an incentive mechanism for a commercial P2P streaming system. We base on the taxation mechanisms defined in [1] and [2] to establish the utility functions of our model. From there, we infer the price-discount constraints and apply them in a P2P service with billing model based on QoS levels. To evaluate the qualitative effect of the model, we use a case study that captures the users’ and provider’s welfare in the system.

Despite the increasing support and innovations in P2P systems, bypassing the server role impacts the traffic control and security. Yet mechanisms to encourage users collaboration and avoid malicious behavior, are an ongoing challenge for multimedia live streaming systems. Moreover, the existing P2P algorithms face the challenge of continuous quality of service (QoS) assurance upon a system scale.

We conclude a monetary remuneration to be a fair incentive for both the provider and the participants in the multimedia streaming system, provided it complies to the established constraints. Relying on this model, a content provider can establish a commercial service for a multimedia streaming service, based on quality of service levels. The discount incentive can additionally motivate the users for increased cooperation and strengthen the system’s integrity.

II. RELATED WORK

A P2P streaming system founds on the total bandwidth circulating in the overlay. This makes the incentive mechanisms a crucial part of a P2P algorithm used to stimulate users for increased cooperation of their free bandwidth. These mechanisms also should address the negative behavior and deal with malicious users who threaten the system.

The literature offers extensive research in this field and so far, various mechanisms have been presented to generate an increased productivity and user-friendly environment. Basically the incentive mechanisms are divided in: reciprocal, taxation, reputation-based and game-theoretic.

Reciprocal mechanisms can be direct and indirect [3]. The former represents a pair-wise incentive as in the PULSE system [4], based on the tit-for-tat strategy and it was initially proposed in file sharing systems due to its fair approach. Liu [5] proposes to combine tit-for-tat strategy with multiple layered video encoding. A similar mechanism to tit-for-tat aimed for P2P streaming services has been introduced by
Ngan, et al. [6]. They suggest temporal reconstruction of the overlay to distinguish nodes with selfish behavior and avoid free riders, for the price of increased overhead.

Taxation mechanisms use the optimal income taxation concept in the economy to establish different tax rates for peers with different capacities. In their paper, Chu et al. [1] motivate high capacity users to contribute with the entire available bandwidth in order to compensate for limited performance of the low capacity users. The tendency of such altruistic approach is to achieve a general system welfare by improving the overall system’s performance and the perceived video quality by the users. Yang, et al., [3] incorporate linear-taxation incentive mechanism into SVC-based layered media delivery towards aware neighbor selection.

Reputation-based mechanisms calculate the global reputation score for every peer in the system retrieved from the feedbacks of all of the peers who have interacted with this peer.

Examples of systems based on reputation include: EigenTrust [7]-uses the sum of positive and negative ratings and pre-trust peers to compute the global reputation scores; PowerTrust [8]-implements a trust overlay network to model the local trust and reveal feedback relationships among peers; PeerTrust [9] introduces a transaction-based feedback system to integrate it into a model for evaluating the trustworthiness of the peers.

Game-Theoretic incentives use the game theory approach to implement strategic play among the participants in the streaming system. Every peer tries to optimize his play, that is, maximize the amount of data received while minimizing the amount of data transmitted. Lin et al. [10] provides a game-theoretic framework to model player’s behavior and design incentive strategies for a P2P live streaming.

So far, we registered no commercial streaming service that bases on the perceived QoS to establish a monetary price model. We base on the taxation model idea to define a utility model for a P2P streaming system. As incentive we suggest a novel discount based approach as a solution towards increased users’ cooperation and decreased free riders and malicious users.

III. PROPOSED INCENTIVE MODEL FOR P2P STREAMING SYSTEMS

Deploying P2P streaming service in a centrally controlled system brings equally many opportunities to the content providers as to the users. In a P2P streaming service with a subscription or on-demand billing model, the idea of a remuneration-based policy is to achieve an increased participation and collaboration among the users by sharing their free upload bandwidth. The cooperative users are rewarded with a discount applied on the initial price proportionally to the amount of shared bandwidth.

A. Utility modeling

We want to model the benefit of the discount from both provider’s and user’s point of view. To that end, we refer to the work in Chu [1] and [2]. In these P2P incentive models, the authors work with a utility function inferred from the linear taxation studies in the economy, to ensure a budget balance. After some approximations, the model is then assimilated in the distributed communication networks to represent the marginal effect of the bandwidth on the user’s viewing experience. Here we adapt and extend those functions to apply to a monetary based streaming system.

User’s utility function $u_u(r, f)$ express the general streaming experience of a participant in a multimedia streaming. It encapsulates the user’s benefit of watching the video and cooperating in the system together with the cost the user pays for receiving and forwarding the content. The user’s utility function serves as an indicator for the individual welfare in the streaming and therefore it should always have a positive value:

$$u_u(r, f_i, F_i) = b_i(r, f_i) - c_i(r, F_i) > 0 \quad (1)$$

The benefit $b_i(r, f_i) = \lambda (\sqrt{r_i} + d f_i)$ models the user’s overall satisfaction of the streaming service. The first member captures the benefit of the perceived video quality. It is a
monotonically increasing and concave function that expresses the diminishing bandwidth for the perceived video quality as the bitrate increases. The coefficient \( \lambda > 1 \) indicates the importance of the incoming bandwidth for the streaming content and we set it to \( \lambda = 2 \) [2].

In an incentive model based on discount, the benefit function should also include the benefit of the received discount for the shared bandwidth. In the second member, \( d \) denotes the discount per user’s forwarding bandwidth unit \( f_i \) and \( r_i \) is the bandwidth the user receives during the streaming. We assign the same importance \( \lambda \) to the second member since the discount is very important to the overall user’s benefit.

The cost \( c_i(r_i, F_i) = \alpha (p r_i + \sqrt{F_i p_i(f_i, F_i)}) \) indicates the aggregated cost the user pays for watching a streaming content and the cost of forwarding the content to the other users. \( p_i(f_i, F_i) = \beta \frac{d}{\alpha f_i} + (1 - \beta) \left( \frac{\sqrt{F}}{\alpha f_i} \right)^2 \) is the fractional cost to use \( f_i \) given \( F_i \), \( p \) stays for price per bandwidth unit \( r_i, F_i \) is the user’s maximum upload bandwidth, \( \alpha = 0.25 \) indicates the desire to forward the video and \( \beta = 0.5 \) indicates the importance of the two components: the direct forwarding cost, \( (\frac{d}{\alpha f_i})^2 \) and the congestion cost \( (\frac{\sqrt{F}}{\alpha f_i})^4 \). For further details on the utility modeling, the readers may refer to [1] and [2].

**Provider’s utility function** \( u_p(r_i, f_i) \) indicates the provider’s benefit for offering the service to the users decreased by the remuneration cost returned to the cooperative ones.

\[
    u_p(r_i, f_i) = b(r_i) - c(f_i)
\]

Provider’s benefit \( b(r_i) = n \lambda p r_i t_v \) indicates the provider’s revenue per user for the offered content such as: football match, live-concert, a keynote presentation, a press-conference etc. \( t_v \) denotes the video duration. The benefit is tightly-coupled to the established price model in the streaming service. We assign the same coefficient \( \lambda \) to the benefit in order to indicate the same importance of the provider’s revenue as the discount is to the users.

Provider’s cost \( c(f_i) = \alpha n d f_i t_f \) is the total monetary remuneration the provider offers to the users who share their free bandwidth. We denote users’ average forward bandwidth as \( f_i \) and \( t_f \) indicates the time a user needs to disseminate the video to his successors, \( t_f \leq t_v \) to denote the possibility of peer’s sudden departure or fail and \( d \) denotes the discount per unit of shared bandwidth. We use the same coefficient \( \alpha = 0.25 \) as in the user’s cost function, to indicate the desire of the provider to offer a discount to the user.

Having defined the provider’s utility per user, we can establish the constraint for the aggregated provider’s utility that depends on the total number of users \( n_i \). The users can be heterogeneous according to the video quality they receive and the forwarding capacity they share.

\[
    U_p(n, r_i, f_i) = \sum_i n_i \left( \lambda p r_i t_v - \alpha d f_i t_f \right) > 0 \tag{3}
\]

Form these equations we can establish the general price-discount restrictions as a function of the received \( r_i \) and forwarded \( f_i \) bandwidth and the price for the streaming \( p \). Equation 1 is a necessary condition for the price-discount constraints to satisfy the users’ expectations. A sufficient condition, equation 3, is that the discount per user doesn’t exceed the initial price a user pays. As additional constraint, the provider may limit the discount per user to a maximum of 50%.

\[
    \begin{cases}
        \alpha (p r_i + \sqrt{F_i p_i}) - \lambda \sqrt{r_i} < d < \frac{\lambda p r_i}{\alpha f_i} \\
        d < \frac{0.5 \lambda p r_i}{\alpha f_i}
    \end{cases} \tag{4}
\]

It may be of a crucial interest for the provider to tune the price-discount \( p/d \) trade-off under the above condition. This discount incentive model rewards the users for being cooperative and partially returns them the invested money. From our point of view, a remunerative price model is a promising solution for commercial P2P based streaming. Such a model can bring mutual benefit to both the provider - to motivate increased participation and popularity of the service and the users - to choose this service and actively cooperate. Provided the users announce the bandwidth they are willing to contribute, the provider can rely on the utility constraints to calculate the discount values for other similar billing models as well.

**IV. Utility Application in a P2P Streaming System**

In this section we apply the utility functions to a billing model of a commercial P2P streaming system. The basic idea is the following: the provider offers a HD video to the users...
with the possibility to stream it with different levels of QoS. Today this can be achieved by using different techniques for video transcoding. Some of them, MDC and SVC are common and widely used techniques in the P2P systems. These transcoding mechanisms divide the video in several portions (called chunks) or sub-streams that carry a basic portion of the entire video with a low quality. Combining multiples or receiving all of these sub-streams, increases proportionally the perceived video quality. As presented previously, [11] an example billing model in a P2P system can be a granulated pricing model based on a scalable video quality. The content provider can establish multiple QoS based pricing schemes and charge accordingly. We sketch briefly hereby, the proposed billing model to better understand the upcoming experiments.

Figure 1 depicts the basic idea of the streaming system. The content provider offers three different prices for the streaming service, classified in gold, silver, bronze packets. As explained, the provider divides the video in multiples of sub-streams, and disseminates each of them in a separate sub-tree. Note that we use a multi-tree overlay in the example to better represent the quality of service levels. The discussion of the P2P topology choice is out of scope for this paper. The gold packet characterizes with best streaming quality and therefore it is the most expensive. This means the users get the entire video definition (full quality) with low latency, jitter and packet loss. Therefore they get connected to all subtrees in the multi-tree topology. To assure low latency and jitter, the gold users are mostly placed on the higher levels of the subtrees, as the picture shows. The silver and the bronze packets consequently, offer a lower video qualities with increased latency, jitter and packet loss. Therefore the silver users are assigned to less sub-trees (for example 18 out of 20 ) and the bronze users appear in only, for. ex. 15 sub-trees on the lower levels.

To formally represent the streaming service and make a fair modeling of the prices, we need to make some assumptions and assign statistically inferred values to some of the variables in the utility functions. To that end, we base on our previous experience with video systems on the one hand and use the data presented in the papers [1] and [2] on the other. The authors use live event traces to set up the parameters for their experiments. To model the fraction of gold, silver and bronze users in the system, we set up several example cases, Table 2. Similarly as registered in the life events described in the papers, we choose a total of 1500 users to be participating in the streaming system.

In a previous research [12], we used video encoded with 500Kbps. However, today the streaming video can reach a quality of more then 1.5 Mbps for high definition [13]. Following are the rest of the parameters we use in our experiments:

- **Tree depth**: $h = 3$. We choose this value in order to achieve a minimum latency at a leaf level in the sub-trees (three hops from the video source).
- **Video bitrate**: 1.5Mbps encoded in 20 equal stripes of 76.8Kbps bitrate.
- **Quality level**. Gold users receive all 20 stripes for best quality; silver - 18 stripes or 1.35Mbps and bronze - 15 stripes - 1.125Mbps.

#### A. Modeling welfare in the system

To better understand the utility and represent its qualitative effect over the system’s welfare, we adapt the utility functions 1 and 3 to model the previously described billing model. Let’s say that the number of users in the system is $n = n(g) + n(s) + n(b)$, where $n(g)$, $n(s)$ and $n(b)$ are the number of users choosing each of the three different price packets - gold, silver and bronze. We denote $n_h(g)$, $n_h(s)$, $n_h(b)$, $n_t(g)$, $n_t(s)$ and $n_t(b)$ as the number of gold, silver and bronze, high and low capacity users respectively. The receiving bandwidth changes according to the quality levels, so $r_g$, $r_s$, $r_b$ represent their entitled receiving video bit rate. The cooperation is expressed with a percentage $k$ of the total users in the system.

1) **Users’ welfare**. Based on the previously defined variables, we can represent the aggregated value for the user utility. The metric in the literature used to represent this values is called welfare. We denote $W_u = B_u - C_u$, to express the users’ welfare, where $B_u$ is the total users’ benefit decreased by their total cost $C_u$:
$B_u = \lambda k \ast [(n(g) \sqrt{T_g} + n(s) \sqrt{T_s} + n(b) \sqrt{T_b})$
$+ (n_h(g) d_h(g) + n_h(s) d_h(s) + n_h(b) d_h(b)) \ast f_h$
$+ (n_l(g) d_l(g) + n_l(s) d_l(s) + n_l(b) d_l(b)) \ast f_l)]$

(5)

In the cost equation, $d_h(g), d_h(s), d_h(b)$ and $d_l(g), d_l(s), d_l(b)$ stand for the discount for gold, silver and bronze high and low capacity users respectively. $F_h$ and $F_l$ express the maximum user’s forwarding capacity, while $p_l(h)$ and $p_l(l)$ are the fractional costs for the high and low capacity users, as stated before.

$C_u = \alpha k \ast [(n(g) p_g + n(s) p_s + n(b) p_b)$
$+ (n_h(g) + n_h(s) + n_h(b)) \ast \sqrt{F_h} \ast p_l(h)$
$+ (n_l(g) + n_l(s) + n_l(b)) \ast \sqrt{F_l} \ast p_l(l)]$

(6)

2) Provider’s welfare: Similarly to the users’ welfare, we base here on the provider’s utility equation 3 to represent the provider’s welfare. The provider’s welfare, $W_p = B_p - C_p$ represents hit total benefit $B_p$ decreased by his total cost $C_p$. The benefit is $k$ independent, because the cooperation doesn’t affect the provider’s revenue (all users pay the packet price regardless of the willingness to cooperate).

$B_p = \lambda \ast (n(g) r_g + n(s) r_s + n(b) r_b)$

(7)

The total cost is tightly coupled to the cooperation level and the fraction of high-low capacity users:

$C_p = \alpha k \ast [(n_h(g) d_h(g) + n_h(s) d_h(s) + n_h(b) d_h(b)) \ast f_h$
$+ (n_l(g) d_l(g) + n_l(s) d_l(s) + n_l(b) d_l(b)) \ast f_l)]$

(8)

We use the equations for the users’ welfare $W_u$ and the provider’s welfare $W_p$ in the experimental representation that follows.

B. Experimental evaluation

In this section we perform some experimental calculations of the utility functions over the system’s welfare. We want to visualize the influence of the three factors: users’ forwarding capacity (high, low), cooperation level (100%, 80%, 50%, 20%, 0%) and the ten fractions of users for different quality levels - Table 2 over the system welfare. For this, we calculate the aggregate users’ and provider’s utility.

User’s and provider’s individual utility. Initially we represent the user’s and provider’s utility change for high and low capacity users. Figure 4 shows the user’s and provider’s utility dependency on the three quality level groups: gold, silver and bronze. As expected both the user’s and the provider’s utility decrease linearly in the same manner. Higher the price the users pay to watch a video, higher the provider’s utility.

Likewise, higher video price increases the the users’ perceived video quality and therefore increases their utility. Note that the difference in the utility between high and low capacity users appears due to the ability of high capacity users to achieve a higher aggregate discount compared to the low capacity ones. The provider’s utility, on the other hand is almost independent of the forwarding capacity, thus the utility difference is neglected.

Users’ welfare. Let’s now focus on the total users’ utility in the system, i.e. the welfare and see its relation to the user profiles. Figure 3 shows the users’ welfare change for the different cooperation levels, as a function of the user group fractions. We note that the total system’s welfare get higher as the cooperation in the system increases. Figure 3(a) depicts the values of user’s welfare when 20% of the users have high forwarding capacity. Compared to the case on Figure 3(c), for 80% high capacity users, the system’s welfare is lower and it increases as the number of high capacity users increase. This is due two the fact that high capacity users potentially increase the total discount in the system, since they can contribute more bandwidth and therefore increase the total discount. Of course, this is conditioned by the cooperation level, as less cooperation gets less dependent on the number of high capacity users, but more cooperation increases the welfare proportionally to the number of high capacity users.

Provider’s welfare. In this part, we represent the analysis of the provider’s welfare. In the first experiment for simplicity, we present the case when 80% of the users are high capacity, to capture the welfare dependency on the quality level groups for three cases: all users altruistic, 50% cooperative and all users selfish, Figure 5. The results show increased welfare for the user groups 1, 2, 5, 8, 10, where the fraction of gold and silver users dominates the cheaper bronze packet. Also we note that the provider’s welfare decreases as the cooperation increases, but with a small difference. The reasoning behind this is that, increased cooperation raises the total discount, which decreases the provider’s welfare. The benefit that the more expensive packets bring however, dominates the welfare and therefore overcomes the effect of the increased discount. This confirms the incentive model to be of a general benefit
for both the users and the provider. A billing model based on remuneration for the contributed bandwidth, encourages the users for increased cooperation. Increased interest in the streaming service, brings additional credit to the provider, both monetary and in terms of infrastructure.

Now we want to analyze the influence of the cooperation on the provider’s welfare, with respect to the number of high capacity users. To that end, Figure 6 shows the provider’s welfare for the three different fractions of (high,low) capacity users for all the cooperation levels. We note that when all the users are selfish (0% cooperation), the provider’s welfare is the same regardless of the fraction of high capacity users. This result is expected, since the uncooperative users don’t generate any discount and therefore the welfare stays independent on the peer’s heterogeneity. The provider’s welfare decreases however, as the cooperation increases in all the three groups, because increased cooperation increases the discount, which on the other hand, reduces the provider’s welfare. We note however that this difference is small and this is because increased cooperation increases provider’s benefit, as more cooperative users, save provider’s bandwidth provision. Therefore this cooperation increases the benefit and maintains the welfare difference small. Finally we note that the provider’s welfare is highest when 20% compared to when 80% of the users are high capacity, but this difference is negligible. This confirms the previous observation that more high capacity users, increase the system’s bandwidth reserves which is a critical resource in a P2P system. Having enough bandwidth resources, improves the system’s integrity and with this - the provider’s welfare.

V. CONCLUSIONS AND FUTURE WORK

The P2P dynamic nature increases a system’s vulnerability in the presence of uncooperative and malicious users, as they impact the system integrity and the users’ perceived QoS. In this paper, we presented an incentive mechanism for a P2P streaming system based on monetary discount. We based on the utility model defined in the taxation incentive schemes and adapted it for a commercial streaming service based on multi-tree overlay. To evaluate the qualitative effect of the model, we made some experimental evaluations that depicted the users’ and provider’s welfare in the system. We’ve noted that the users’ welfare increases with the cooperation level and with the number of high capacity users. For the provider, increased cooperation decreases the welfare but the difference between the cases when all users are selfish and all of them are cooperative is negligible. Increased fraction of high capacity users affects at a higher extent the total welfare. What mostly affects the provider’s welfare is the quality groups fraction, since increased number of high quality users, increase the overall benefit. To summarize, we can conclude that a billing model based on quality of service levels for the perceived video using incentive model based on remuneration, is feasible solution that can increase the system’s welfare. Moreover the guidelines of this model can be implemented in a commercial streaming system to boost increased participation and improver the overall’s systems integrity. As a future work, we plan to extend the analysis on a streaming system leveraged in the cloud and implement an algorithm for a QoS based allocation of the users in the system.

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