Business Model with Discount Incentive in a P2P-Cloud Multimedia Streaming System

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***Abstract*—Today P2P faces two important challenges: design of mechanisms to encourage users' collaboration in multimedia live streaming services; design of reliable algorithms with QoS provision, to encourage the multimedia providers employ the P2P topology in commercial live streaming systems. We believe that these two challenges are tightly-related and there is much to be done with respect. This paper analyzes the effect of user behavior in a multi-tree P2P overlay and describes a business model based on monetary discount as incentive in a P2P-Cloud multimedia streaming system. We believe a discount model can boost up users' cooperation and loyalty and enhance the overall system integrity and performance. Moreover the model bounds the constraints for a provider's revenue and cost if the P2P system is leveraged on a cloud infrastructure. Our case study shows that a streaming system provider can establish or adapt his business model by applying the described bounds to achieve a good discount-revenue trade-off and promote the system to the users.**

***Index Terms*—incentive, P2P, cloud, streaming, discount, multimedia, business**

I. INTRODUCTION

P2P brought an alternative to the client-server content distribution. It introduced an application level routing among the users–called *overlay*–based on dynamically formed connections. Users may join and leave the overlay without restriction.

The important momentum of P2P was recognized in systems with heavy server load, caused by users' overwhelming demand operations. A typical example is bottlenecks caused by traffic output demand in streaming systems. This kind of server independent cost-efficient overlay, engaged numerous users to a cooperative way of contents share and retrieval.

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 P2P algorithms should guarantee continuous quality of service (QoS) upon a system scale.

We organize this paper in two parts. First we briefly introduce P2P and show the tight relation of the multi-tree overlay topology with the user behavior in the system. Today it is challenging to establish an incentive mechanism for a commercial live streaming system. We follow up some of the existing studies that address uncooperative and malicious behavior in P2P streaming systems.

In the second part we describe a P2P-Cloud system for multimedia streaming with a business model based on monetary discount. So far the increasing offer of the cloud providers facilitates a specific type of infrastructure that liberates a client's service from irrelevant features–*pay for what you use*. The dedicated underlying infrastructure spread across continents to improve the system's QoS and the users' experience. We believe cloud is a good asset with favorable price offers and flexible infrastructure to leverage commercial P2P-assisted multimedia streaming services.

As of the above reasons, the described system relies on cloud infrastructure to host the multimedia service and set up on P2P to redistribute the video among the users. We establish the constraints for the provider's revenue that bound the feasibility of the business model. Furthermore we present an analytical bounds for the provider's infrastructure cost in the established P2P-Cloud scenario.

Finally by analytical case study we found out the discount to be a potentially beneficial incentive strategy for both provider and participants in the multimedia streaming system, provided it complies to the established constraints.

II. P2P LIVE STREAMING

In this section we describe the concept of P2P and its use for multimedia streaming applications. Latter we focus on a multi-tree P2P topology and describe the relation between the user behavior and the overlay.

A. P2P overview

P2P represents a cooperative model of interconnected users called *peers*. The integrity of P2P relies on the overlay network formed among the users and depends on the aggregate bandwidth in the system. When it appeared, the initial goal of P2P was to support scenarios with voluntary participation, where the users share their resources (ex. upload bandwidth, computing capacity) among each other. P2P inspired research in algorithms for overlay construction that aim on fair bandwidth distribution across the users in the overlay.

This P2P idea found an immediate application in: file sharing systems, cooperative on-line games and multimedia streaming–live and on-demand with the appearance of Internet TV and content delivery networks (CDN). BitTorrent[1], CoolStreaming[2], PPTV[3] and SopCast[4] are only several pioneer

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[1] http://www.bittorrent.com
[2] http://www.coolstreaming.us
[3] http://www.pptv.com
[4] http://www.sopcast.com

applications that gained popularity among the file sharing and streaming applications. Unlike the client-server model where the contents are fetched from the server once per every client, in P2P a content can be redistributed repeatedly among the users. This is a fundamental difference that helps P2P enhance the system performance and avoid server bottleneck.

Although widely accepted and increasingly used, P2P faces an important drawback–the inability to prevent abusive and uncooperative users to join 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. Livestation[5] with its premium subscription, BBC's iPlayer1.0[6] (being P2P-based until 2008), BitTorrent Live [7], Octoshape[8] and Zattoo[9] are few examples of commercial P2P-assisted live streaming services.

Rodriguez et al. [1] observe the issues regarding commercialization of P2P algorithms. They point out the necessity to explore incentive models based on economic savings, access to premium content or community-based alternatives.

It is challenging to establish an accurate business model in a P2P-based system. The system continuously change as new peers arrive and depart. Moreover uncooperative and malicious users impact severely the overall integrity of the system. Therefore - incentive mechanisms are necessary to motivate such users to actively participate in the system.

B. P2P streaming topologies

In the literature, the P2P overlay topology is classified in two general categories: multi-tree (tree as its subcategory) and data-driven randomized (also called mesh).

1) Mesh: This approach organizes the users in a randomly formed mesh, where the video is sliced in chunks and sent to the users. Since the system we use in the paper bases on a multi-tree topology to describe the business model, we omit from details about mesh topology. For through description, Liu et. al, [2] present a comparative analysis of the two overlays employed in a streaming scenario.

2) Multi-tree: For the system described in the paper, we base on a multi-tree overlay [3] to show the topology setup effect on the QoS of the streaming system. We choose multi-tree over mesh mostly because of the possibility to intervene in the topology creation, unlike the mesh, which is randomly created. Moreover the business model we explain latter, bases on three levels of QoS and therefore we found convenient to express the quality levels through multiples of sub-streams.

In a multi-tree overlay, the users take part in multiple d-ary sub-trees. The streaming server is the root of the tree. He divides the video with streaming rate r in m sub-streams and disseminates them deeper in the sub-trees. The sub-trees are formed in a breath-first manner, upon client's arrival. Figure 1 depicts a typical multi-tree overlay with a server as a root of the streaming content and two separate sub-trees. The tree has a depth $h = 3$ and degree $d = 2$.

The tree degree defines node's maximum number of children, while the tree depth is the maximum number of traverses from the root to the furtherest leaf. Since the tree is formed in a breath first manner, higher tree degree results in wider sub-trees and connects more users at higher tree levels (close to the root). Bigger depth, in contrast, increases the number of steps a streaming content traverse on his way to the leafs, hence increases the delay at lower levels.

Therefore by adjusting the multi-tree topology, the provider can either reduce the bandwidth demand by reducing the tree degree as long as the delay is sustainable, or scale the infrastructure to increase the bandwidth supply and decrease the total delay. The previous analysis states for a valid $f_i \geq r_i$ pre-condition, i.e. the peer should contribute at least as much forward bandwidth f_i as he amount he receives r_i. The contrary will provoke elapsed brunches in the multi-tree environment. Therefore the streaming content provider should account in advance the amount of peers' bandwidth to share in order to build an optimal overlay topology.

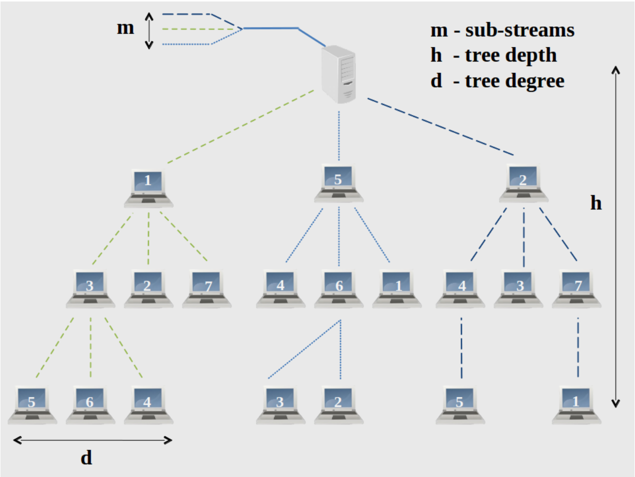

Fig. 1: SplitStream[3] overlay topology

C. Behavior in a P2P streaming system

We focus on the influence of both cooperative and uncooperative users in the system based on their position in the streaming trees. To remind, P2P relies on collaborative network of users that are expected to contribute, which in practice, is not always the case. Cooperative users share determined upload bandwidth with other users in the system, unlike the uncooperative also called *free riders*, who enjoy the streaming but don't forward the video to the other users in the tree. Malicious peers join the system exclusively to harm its integrity and the QoS.

Cooperative users. In a multi-tree overlay these users improve overlay construction and contribute to more balanced sub-trees. Moreover they foster system's performance increasing shared bandwidth reserves. According to the multi-tree

[5] http://www.livestation.com

[6] http://www.bbc.co.uk/iplayer/tv

[7] http://live.bittorrent.com/

[8] http://www.octoshape.com/

[9] http://zattoo.com/

constraints in SplitStream[3], to achieve a feasible overlay a client contributes upload bandwidth at least as the amount he downloads. For a well-balanced overlay, authors suggest to connect each user as inner node in only one sub-tree, and as leaf in the rest, Figure 1. Sweha et al. on the other hand [4], suggest connecting the users in minimum number of sub-trees. From those, they appear as inner nodes only in a number of sub-trees corresponding to their upload bandwidth.

Imagine cooperative users with high upload bandwidth. Following the above recommendation, a provider can put them on a higher level in a number of sub-trees equivalent to the amount of their upload bandwidth. This opens proportional number of connections for additional high level users. As a conclusion, in a multi-tree P2P scenario, cooperative users make significant contribution if placed higher in the sub-trees.

In a mesh overlay, due to its dynamic nature, a cooperative users increase the availability of the streaming content to the peers across the entire overlay. They also improve the overlay integrity by forming a more stable connections among the peers.

Uncooperative users. In a voluntary system as P2P is, the presence of uncooperative users is inevitable as a result of the optional bandwidth share and a peer's will to increase for free their personal welfare.

For a multi-tree overlay, this generates elapsed branches in the sub-trees where the user appears as inner node, leaving his successors as orphans. Higher level free riders make big impact to the overlay integrity as they leave empty connections and hence provoke sub-trees mis-balance. Uncooperative users should be always connected at a lower tree level to reduce the impact on the tree expansion and to avoid system's resource consumption.

Hosting selfish users in mesh overlay impacts to the same extent, since the peers would lack the resources of the selfish peer and thus experience a lower video quality. The selfish node on the other hand take the advantage of the available bandwidth of the peers he is connected to.

Malicious users. Unlike self interested users, malicious ones are even worse candidates who threaten the system integrity. They exploit the system by harming other peers and prevent them to enjoy the streaming. They do this by performing various actions such as: presenting false identities, data drop and data pollution, collusion attacks with other peers, assigning false reputations, etc. It is yet a challenging task to detect and deal these users even for a widely used P2P streaming systems.

III. INCENTIVE MECHANISMS IN P2P STREAMING

For best user experience, P2P live streaming requires enough shared bandwidth and topology integrity. Therefore the presence of incentive mechanisms is crucial to deal with negative behavior and generate more productive and user-friendly environment. The literature offers plenty of information on incentives for sharing in P2P. In essence, the aim is to motivate users to participate actively in the distribution of data streams by using their spare upload bandwidth. The authors in [5], divide incentive mechanisms applied to P2P media streaming into four groups: reciprocal, reputation-based, game-theoretic and taxation-based.

Reciprocal mechanisms base on the tit-for-tat strategy and it is mostly used in file sharing systems. Peers only exchange resources with neighbors with similar upload rates. Occasionally, they allocate their own upload capacity by assigning slots - first to those users with more transfer rate. In this scheme, free riders are alienated as they don't reach friendly relationships with their neighbors.

In [6] there is an interesting instance where a tit-for-tat mechanism is combined with multiple layered video encoding. Layered videos provide better quality when more layers are received, thus, by using a tit-for-tat strategy, users who transmit more layers receive more back and get a better video quality as a result. Ngan [7] proposes a mechanism similar to tit-for-tat aimed for P2P streaming services. He suggests temporal reconstruction of the overlay to distinguish nodes with selfish behavior and avoid free riders. This however increases overhead any time the tree is reconstructed.

Limitation. Peers can only contribute to other peers with similar contribution levels.

Game-Theory. Bases on game theory approach to implement strategic play among the participants in the streaming system. Every peer (strategic player) tries to optimize his play, that is, maximize the amount of data received while minimizing the amount of data transmitted. Lin et. al [8] provides a game-theoretic framework to model player's behavior and design incentive strategies for P2P live streaming.

Limitation. This approach faces a difficulty to deal with peer churn because of the precondition that every peer should stay until the end of the game, i.e. the multimedia streaming session.

Taxation. All the previous mechanisms tend to reward users based solely on their contribution. However, those peers with less capabilities in terms of bandwidth can be, in some cases, punished for the lack of resources rather than for the lack of willingness to participate. Chu [9] motivates users to contribute with the entire available bandwidth, i.e., users with high upload bandwidth get encouraged to participate with more bandwidth than they need to receive the whole stream, in order to compensate for the "less fortunates". This altruistic approach aims to achieve a sort of social-welfare in the system where, ideally, more users are allowed to receive media in good conditions. Yang et. al in [10] incorporate taxation based incentive mechanism into QoS aware neighbor selection algorithm.

Limitation. Free rides can however profit in systems with this mechanism unless dealt properly, since the altruistic nature of taxation has no means to deal with them.

Reputation-based mechanisms deal with providing a global rating for every user in the system. This score improves with the user's contribution. Users consult the reputation of the possible receivers and choose content suppliers. A reputation is an indirect-reciprocity mechanism. This means, as opposed to the reciprocal systems based on mutual relation of two peers, reputation is global. The main drawback of reputation for media streaming is that it can take time to build up. However, [11] uses a reputation history to improve on his reciprocal system, allowing users to perform informed choices when they select future candidates. This history bases on the previous interactions among the users.

In his study, Li [12], claims that reputation and credit-based incentive mechanisms although successful in a file-sharing P2P applications, are unlikely to work in a streaming scenarios due to limited time framework. As an open issue, he encourages further investigation for incentive models and price establishment in P2P streaming.

Limitation. Peers with poor BW are likely to have lower reputation scores and thus lower priority in selecting which peer to obtain the stream of; a lack of reputation history for new coming peers; high reputation peer can loose stimulation to contribute further in the system; free-riders can abuse the grace period given to newcomers to take advantage of the system.

Apart from the described incentives, the literature offers models based on combinations of some of the above techniques. One example is the approach to introduce the social network data into game-theory approach as incentive in file-sharing [13].

An example of a commercial service on the Internet is to classify the clients in premium and basic membership based on subscriptions. Premium users usually pay monthly/yearly price and enjoy certain privileges such as - commercial-free, complete access to all services. Basic users on the other hand, are charged per content or have restricted access of contents and receive commercials during the streaming.

We registered no commercial streaming systems however, that uses QoS of video in their business models. In the next section we present a case study for a business model based on QoS which applies a discount-based incentive.

IV. DISCOUNT INCENTIVE APPLIED TO P2P-CLOUD STREAMING SYSTEM

The trend of using cloud infrastructure to leverage multimedia services has increased in the last years. In a recent study [14] we showed that using cloud-based P2P streaming, increases overall system performance and improves QoS for the participants in the multimedia streaming service.

Deploying a P2P streaming service in a centrally controlled system opens as many possibilities for the streaming content providers as for the users. The *easy-to-use* and *on-demand* cloud infrastructure saves for provider the cost of underutilized on-premise resources. This traces the way for innovative and user-oriented granular price classification to define a good business model for streaming service in the cloud.

A. Business model description

In this section we base on our previously proposed multimedia streaming system [15] to illustrate what are the provider's cost constraints to establish a commercial P2P service. We also describe discount incentive model based on money and discuss its application on the system. This system relays on cloud infrastructure for better QoS and service-scale in case of overload.

Figure 2 depicts the system topology. There is the server of the streaming content in the cloud and a P2P multi-tree topology formed among the clients. Before sending to the clients, the video is divided in sub-streams (three in this case) and disseminated in three different sub-trees. The streaming content provider can contract cloud instances in different geographic zones and connect each client in his closest sub-tree. This decreases video delay and facilitates scalability, since once a sub-tree is saturated (no left forward BW for upcoming clients), the system can be scaled on-time in the closest geographic zone.

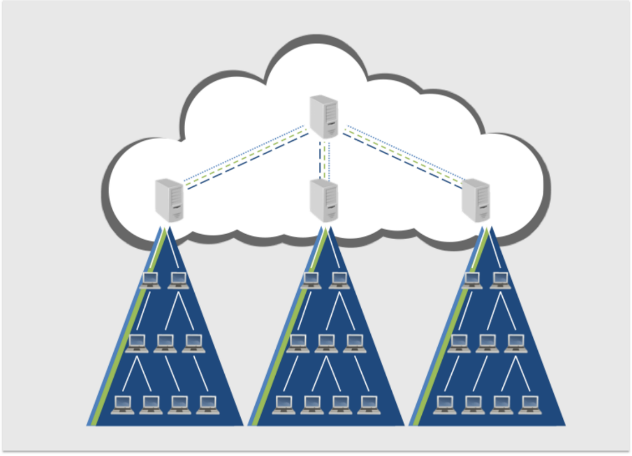

Fig. 2: P2P-Cloud architecture with multi-tree overlay

The business model of the system consists of three types of subscriptions–*gold, silver* and *bronze* defined according to the QoS a client signs up for. Since we discussed previously that the video is divided into various sub-streams, gold clients receive all sub-streams which result in maximum perceived video quality with almost no delay; silver clients consequently receive less streams and experience some delay; and bronze–few streams with more delay. Gold clients get connected to all sub-trees at higher levels, while silver and bronze go to lower levels. Clients can choose a subscription type and connect to the service at the scheduled streaming time, provided they have enough download bandwidth to receive the requested sub-streams. Each client declares if he will participate in the P2P network and the amount of upload bandwidth to offer to other clients. After the end of the streaming, peers are rewarded with discount from the initially payed price–an amount proportional to the shared bandwidth. The system encourages gratis clients to connect provided they contribute with their upload bandwidth. In exchange, they can watch the video for free.

The system uses the multi-tree overlay topology to organize peers in the number of trees according to the quality they want and the price they pay. Heterogeneous peers can be connected at appropriate tree level according to the amount of bandwidth they declare to forward. Invested money will stimulate peers to stay until the end of the streaming session. We believe the commercial model itself decreases the number of malicious users who would pay only to harm, but in case they exist, the provider can penalize them by connecting at leaf positions or simply by expelling them from the system. The children nodes from the elapsed brunches are then reconnected to other trees before they suffer a lower short term quality (but not interruption). The same way free-riders who forward less BW then declared, can be penalized by reconnecting them at a lower tree level and cutting off the discount they receive.

The key driver in this system is the monetary incentive model. That stimulates cooperative behavior and motivates clients to offer spare upload capacity as *bandwidth as a service*. Next, we analyze the discount model and establish a provider's infrastructure cost. Later we apply the profit and cost analysis to the system discussed in this part.

B. Discount-based peer incentive

In a P2P system where users pay a subscription price, the idea behind a discount-based incentive lies in establishing a remuneration policy to motive increased participation and collaboration among the users. The discount applies over the initial price proportionally to the amount of the shared bandwidth. For feasibility of the model, we set up a precondition for the provider–a positive revenue.

Provider's revenue $P(R)$ is money the provider receives form the users for watching a streaming content such as: football match, live-concert, a keynote presentation, a press-conference etc. The revenue is tightly-coupled to the established business model in the streaming service. It depends on the total number of users N_i and the price associated to stream the video P_i. T_v denotes the video duration.

Provider's discount $P(D)$ is a monetary remuneration D_i the provider offers to the users for sharing their bandwidth. We denote a user's total forward bandwidth as f and T_f the time to forward the video to other users. Here $T_f \leq T_r$ to denote peer's sudden departure or fail.

Supposing all users will share their bandwidth, we can establish the general constraints for a discount-based model:

$$P(R) - P(D) = \sum_i N_i(P_i\, T_v - D_i\, f\, T_f) \geq 0 \qquad (1)$$

It may be challenging for the provider to establish price-discount (P_i/D_i) trade-off, such that the above condition states. This discount incentive reward 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.

The equation 1 although defined for a general discount based model, can be adapted to reflect the business model of this system, by defining more variables per price packet, instead of having a unique price per video content. For example, $N_i = P_g + P_s + P_b$, where P_g, P_s and P_b is the subscription price for gold, silver and bronze packet. With appropriate adaptation it can be applied to any discount based model.

C. Provider's cost and revenue

The multimedia contents on the Internet can be either previously stored and streamed to the clients at a certain time (VoD, IPTV), or shown as being emitted - live event streaming. In a cloud scenario, the video can be encoded in a streaming media server on premise or on the same cloud instance. The provider decide to use the cloud, he may add up charges for extended hosting services and tools such as: load-balancers, optimized utilization of instances use across data centers (in case of Amazon[10]), monitoring, etc. These additional services are nonessential for our profit-cost trade-off analysis, so will be omitted in the provider cost calculus. To achieve a general price definition for a live streaming service on the cloud, we abstract from the video source location and define cost constraints per streaming event. From here, the total provider's cost depends on the cost per cloud instance and the data transfer cost to forward the video from the publisher to the directly connected users.

Instance cost $C(I)$. Live streaming, unlike video on-demand, has a time frame limit. To take advantage of the flexible cloud service, a provider may rent an on-demand instance. Cloud providers today charge for the compute instances based on the user/service requirements. For example Amazon EC2 classify on-demand instances on: standard - small, medium, large, extra large; micro; high-memory; high-CPU; cluster-compute; cluster-GPU and high-I/O.

Transfer cost $C(T)$ is a price for the output traffic from the instance to the clients. What shapes this cost, is the streaming video capacity together with the number of clients connected directly to the instance.

Following is the TV provider's cost to stream a video during T_v, on a cloud instance with upload bandwidth capacity $u(I)$ that costs C_i, while the data transfer cost is C_t, across n instances:

$$P_c = C(I) + C(T) = (C_i + C_t\, u(I))\, T_v\, n \qquad (2)$$

The cost depends on the number of cloud's direct connections. In a scenario where all clients are connected to the provider in a star topology, the provider's transfer cost increases linearly with the number of clients. P2P topology instead, decreases the number of direct connections by organizing peers in overlay network. In such case less clients are connected directly to the cloud, which reduces provider's transfer cost.

Finally we conclude that adjusting cost and revenue to abide to the condition $P(R) - P(D) - P_c > 0$, (eq: 1, 2), represents a model for a discount based incentive for the participating peers in the streaming system and essential constraint for a provider of multimedia streaming service.

To calculate price-discount variables for the discussed business model, we developed a tool *TVProviderCostCalculator*[11], based on the provider's cost and revenue equations. Although ti follows the model of the use case streaming system, it is general enough to address similar economic-oriented business models.

Case Study. Due to space limitation, we sketch briefly the results obtained for an example case study. We chose three different groups combinations for number of gold, silver and

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[10] http://aws.amazon.com

[11] http://web.dit.upm.es/irenatr/calculator

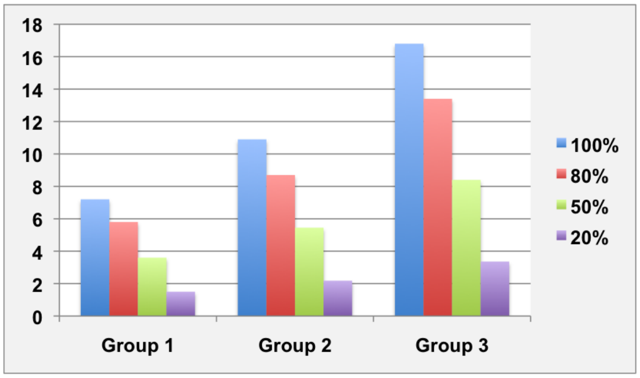

Fig. 3: Three compositions of gold, silver and bronze users and respective discount % for different levels of user cooperation

bronze users and set up a price per streaming content (4, 2 and 1 euros consequently). We set up a discount of 0.5 euro per GB shared. As medium forward upload bandwidth we choose 0.4 GB/h. We want to see how the % of users' cooperation in the system affect the provider's revenue. Figure 3 shows the % (y axis) of the total discount to three groups of users (x axis), for four levels of user cooperation: all cooperative, then 80%, 50%, 20% - cooperative. We note that even in the perfect case when all peers participate, the total discount the provider pays back does not reach 20% of his total revenue. Moreover we consider a remuneration of 12.5%, 25%, 50% off the initial price to be a decent monetary incentive for the peers to contribute to the system. We should note that this example is only to illustrate the outcome of the business model when intuitive values for bandwidth and prices are considered for the evaluation. It confirms the feasibility of discount based approach in a multimedia system under the given bounds. Finally it should serve as a basic discount model which can vary and adapt depending on the particular system and scenario.

V. SUMMARY AND FUTURE WORK

In this paper we initially observed the characteristics of P2P and the challenges it faces for increased adoption in commercial live streaming systems. We sketched the influence of the uncooperative and malicious users to the overall system topology. The P2P dynamic nature increases system vulnerability in the presence of uncooperative users, as they impact the system integrity and the users' perceived QoS.

In continuation we presented a business model with incentive based on monetary discount. The model establishes the constraints for users' satisfaction and provider's revenue in a cloud-hosted P2P streaming service. We find that the discount as a potential incentive in P2P-based streaming systems can contribute to: increased shared bandwidth and better system's performance and user's QoE. Moreover, implemented as a multi-tree overlay with central authority it increases peer's trust and deals better malicious behavior and peer's churn.

Finally we made an analysis for different groups of peer's compositions for four cooperation levels–from all cooperative users to only 20% who share bandwidth and concluded that an appropriately chosen discount and price values can boost up users participation with low effect on the global provider's revenue.

To sum up, economic-oriented live streaming today faces a slow tendency in adopting P2P for large-scale systems. Up to our knowledge we are the first to present an example for a business model based on QoS which applies a monetary discount incentive.

As a future work, we plan to extend the analytical model and study a real live event traces to quantify the benefit of this business model for multimedia providers and users. Moreover we plan to implement the P2P-Cloud system and gather real data to qualify the system's efficiency and measure the user's QoE.

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