Towards an Incentive Mechanism for Peer-to-Peer Multimedia Live Streaming Systems

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Abstract

Incentive mechanisms are essential components of peer-to-peer systems for file sharing such as BitTorrent, since they enforce peers to share their resources and to participate. Recent P2P systems that distribute live multimedia streams take their inspiration from BitTorrent, but have not defined incentive mechanisms appropriate to the nature of continuous media. In this article, we uncover the way that the incentive mechanisms in BitTorrent are not well suited to streaming live multimedia, and based on P2P systems that we have measured, we propose a new incentive mechanism designed for distribution of live multimedia streaming over a P2P network.

1 Introduction

Peer to peer (P2P) systems have demonstrated their ability to provide large scale content distribution in the Internet [1]. This is clearly the case for file sharing P2P applications such as BitTorrent [2] or eDonkey [3]. In fact, work has moved on from file sharing to multimedia streaming of live content such as live TV over P2P networks (P2P IPTV). There are already numbers of P2P IPTV applications deployed on the Internet, inspired by the P2P architecture of BitTorrent [4] such as PPStream [5], SOPCast [6] or PPLive [7].

The P2P architecture of BitTorrent rests largely on the use of a mechanism to align incentives between peers in the system. The incentive mechanism is used to enforce collaboration and exchange of data between peers, so that fairness is respected in the P2P system. However, BitTorrent is originally designed for file sharing and is not adapted for live multimedia streaming. Multimedia flows impose temporal constraints which are not present for mere file distribution and result from the continuous nature of the transmission. Hence peers synchronize with the data each needs. Peers cannot transmit data in return, not because they are uncooperative, but because the nature of the content and the temporal constraints make it pointless. Thus, fairness is not achieved in the P2P system. The nature of the content obsoletes the incentive mechanism of BitTorrent.

In this paper, we present a new incentive mechanism designed for P2P live multimedia streaming applications based on the architecture of BitTorrent. This mechanism allows the evaluation of peers collaboration on other criteria than just the data exchanged. In effect, this criterion is not appropriate to P2P live multimedia streaming systems because of the nature of continuous media. In our solution, the peers are encouraged to collaborate by transmitting information pertaining to the discovering of new data providers. Our mechanism allows to avoid penalizing peers that cannot reciprocate in the exchange of data. It differs from previous ones (such as [8], [9] or [10]) because these mechanisms are based on ranking, trust or selection of peers to evaluate the collaboration of peers in the P2P system. To our knowledge our mechanism is the first to be proposed that functions based on the control information exchanged rather than on the data exchanged.

The next section describes the architecture of BitTorrent and the limitations of its incentive mechanism for live multimedia streaming. After some observations on P2P IPTV systems that we measured the traffic in section 3, we present our new incentive mechanism in section 4. Finally, we conclude and give perspectives in section 5.

2 Architecture of BitTorrent

2.1 Review of BitTorrent Functionality

BitTorrent divides a file into a collection of blocks (*chunks*) to distribute it, and peers have to recover all the blocks to download a whole file. To achieve this, peers exchange with each other a *buffer map*, that is, information

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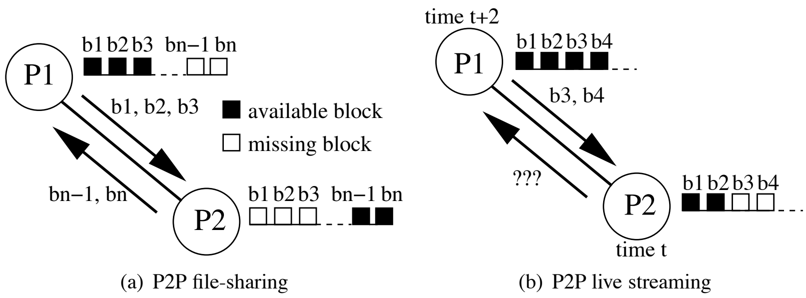


Figure 1. Chunk broadcast for BitTorrent-like P2P systems

about which data blocks they own, and which they want to recover, organizing the P2P network in a transient mesh whose links are between peers depending on their interest in available blocks. To allow fairness between peers in the P2P system, an incentive mechanism is used to enforce collaboration and exchange of blocks of data. The incentive mechanism in BitTorrent rests on reciprocal exchange of data between peers (*tit for tat*). More precisely, a peer transmits a block to another peer if the either transmits one in return. Peers are thus encouraged to contribute to the peer-to-peer system since they are repaid by receiving new blocks. Clearly, whenever a new peer joins without any block, it must be allowed to recover its first blocks without having yet transmitted any (*optimistic unchoke algorithm*).

Since all the blocks of a file must be downloaded before the file can be used, each block has equal importance, and peers need to recover blocks of a file in no particular order without regard for their position in the file (beginning, middle or end of file). This scenario is illustrated in Figure 1(a): Peer P1 has the first three blocks of the file (b1, b2 and b3), while P2 has the last two blocks (bn-1 and bn). In this situation, it is in each's interest to exchange the blocks to augment their collection of blocks.

2.2 Limitations of BitTorrent's Incentive Mechanism

Differently from files, live multimedia streams are consumed on-the-fly as they are received. For a live multimedia stream, blocks do not have the same importance given their position in the flow, since blocks have to be consumed in real time (i.e. on-the-fly). Hence there exists a temporal constraint – which is not present for file distribution – and results from the continuous nature of the transmission. In concrete terms, block b in a flow must be consumed before block b+1 from the same flow to respect the playback time of each block, and to render the flow with good quality.

If we revisit the previous example (Fig. 1(a)), but with a multimedia flow, peer P2 has blocks bn-1 and bn and must already have received blocks before to be able to consume these ones on the fly. In contrast, P1 which has blocks b1, b2 and b3, is not necessarily interested in blocks far ahead (in time). Its priority is to fetch blocks which it can consume soon such as blocks b4, b5 and b6, which are more important to P1 than blocks bn-1 and bn. Finally, each peer finds itself at a different point in the playout, and peers which have received blocks at playout time t+n have received more blocks and are further ahead than peers who are still at point t. Peers at playout point t+n hold blocks that are indeed of interest to peers behind at time t. The opposite is not the case: blocks held by peers behind, at time t, are of no interest to peers at point t+n, since they have already recovered those and are moving ahead. This example is illustrated in figure 1(b). Peer P1 is at playout point t+2 and has blocks b1 to b4, which some are of interest to P2 (b3 and b4). P2 is behind, (at playout point t) and has nothing it can possibly send to P1.

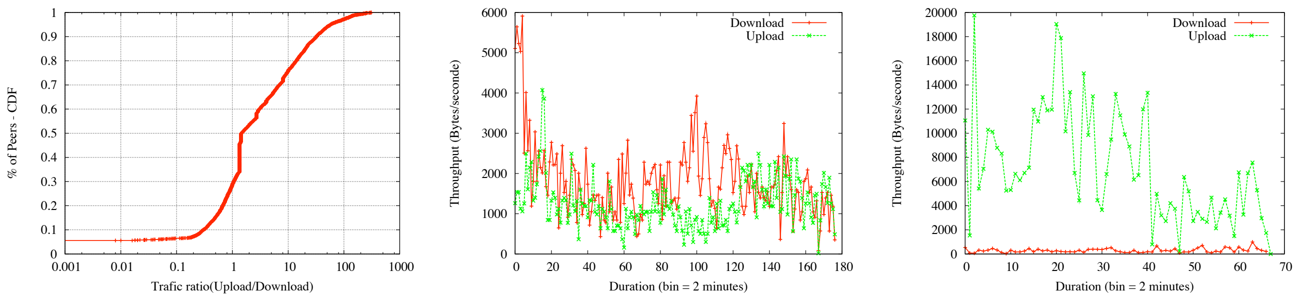
To put this another way, P2 does not transmit data to P1, not because it is uncooperative, but because it is in the nature of the content and the temporal constraints that makes it pointless. Peers synchronize with the data each needs. If peers send data without reciprocation, fairness is not achieved. This is indeed what we observe in the course of our measurements of P2P IPTV systems, and which we present in the next section.

3 Measurement of Real Systems

We performed passive measurement of the traffic generated by the most used P2P IPTV applications at the time of the experiment: PPLive, PPStream, Sopcast. We made our measurement experiments by collecting the traffic in our campus network. During this experiment, we collected the traffic while watching live events (i.e. sports events) since we focus on live streaming. It is intuitive but corroborated by Veloso et al. [11] that the traffic generated by users is not the same whether broadcasted content exhibits a live interest or not. In the following, we present only traffic analysis for PPStream but these observations are similar for all the other applications.

3.1 Observations of Real Systems

Figure 2(a) shows the cumulative distribution function (CDF) of the relationship between traffic ratio (up-



(a) Trafic ratio : Upload/Download

(b) Fair example of traffic exchange between two controlled peers

(c) Non fair example of traffic exchanged between two controlled peers

Figure 2. Traffic analysis for a P2P IPTV application (PPStream)

load/download) between a peer which we control, and all the peers with which it exchanges data. When the ratio is above 1, our peer is altruistic towards another peer; when equal to 1, the exchange is fair; when below one, our peer is taking advantage of the altruism of others. The CDF indicates that 30% of peers are altruistic with our peer. The 70% of peers remaining are beneficiaries of our altruism. Overall, the system is never fair to us, with the large majority being mainly consumers (ratio$>$1) than producers (ratio$<$1).

However, there exists distinct peer behaviour traits. Looking at figures 2(b) and 2(c) we have isolated uplink and downlink traffic, between our peer and others. In Fig. 2(b), the two curves are not the same, but show that two peers try to contribute in the same proportion during their exchange. In contrast, in Fig. 2(c) we can see that our peer has contributed a lot of information while it has received virtually nothing in exchange. The second case (Fig. 2(c)) is clearly the case that is the most likely to happen.

This traffic analysis shows that fairness is not achieved in P2P live streaming systems. These observations illustrate the need for an incentive mechanism which is designed for P2P systems for distribution of live multimedia flows. Such a mechanism must allow all the peers truly to collaborate in the network, even if the continuous nature of the content being distributed mitigates against the transmission of data in a reciprocating manner, something that BitTorrent ascribes to profiteers in the system [12] (*free riders*).

4 Towards a Novel Incentive Mechanism

For P2P live multimedia streaming systems, collaboration of a peer in the P2P network cannot be evaluated merely on the basis of the quantity of data it transmits in its turn at furnishing content. This is due to the continuous nature of the media and its temporal constraints. We propose a new incentive mechanism to P2P live multimedia streaming systems which introduces a new criterion for evaluation of the collaboration of a peer. This criterion will allow us to show whether a consuming peer invests in the exchange or not.

In our mechanism, consumer peers advertise new peers capable to offer data to provider peers. This allow providers peers to discover new sources of data. Thus if a peer transmit no data itself to one of its provider peers, it proves it is collaborating and it is indirectly allowed to receive data. This new type of collaboration encourages peers constantly to find new peers and propose them to its data providers.

The mechanisms for finding new peers in P2P systems have already been well studied [13] and work as follows: each peer can add information which it sends to its neighbors (with its *buffer map*) a list of peers it knows about. Peers forward randomly the list of peers that they have discovered, in a manner analogous to the protocols used for epidemic diffusion (*gossip protocols*).

Figure 3 illustrates the new incentive mechanism we propose. Peers P1 and P2 are in the same configuration as before (Fig. 1(b)). Remember that BitTorrent creates a mesh between the peers which own various blocks of data. In our example, P2 knows P1, P3 and P4. They are ahead the playout time of P2 so they have blocks which are interesting for P2 (P1 is at time t+2, P3 at time t+1 and P4 at time t+4). P2 provides also P5, which is behind (at time t-1). P1, P3, P4 and P5 constitute the neighborhood of P2. They all have their own neighborhood, but for clarity reasons, it is not shown in the Figure.

Since P1, P3 and P4 are situated ahead the playout point of P2, it is highly likely that P1, P3 and P4 are situated at close playout points and are looking for common blocks of data. Because P1, P3 and P4 have their own neighborhood with different content provider peers, these three peers also hold blocks possibly interesting to others. This is the case for P4 that has interesting blocks for P1 (b5, b6). Thus, peers P1, P3 and P4 are certainly interested to establish peering relationship together to exchange blocks of data, but they still do not know each other.

Even though the continuous nature of the media means that P2 is not able to offer data to P1 in return (solid black arrows in Figure 3), P2 can collaborate in the system by transmitting to P1, information about the new potential

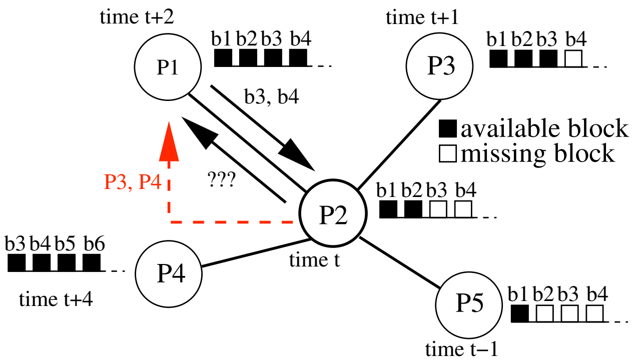


Figure 3. New incentive mechanism for P2P live multimedia streaming

sources of data (red-dashed arrow in Figure 3). P2 is incentivized to find these new pairs and report them to providers.

In our example, P2 inform either P3, P4 or even P5 (or both) about P1. The reaction of P1 according to the new discovered peers is as follows:

- P4 holds blocks which interest P1. P1 and P4 have to organize themselves to exchange blocks of data. P1 has to convince P4 to send it data, by finding new blocks or new sources of data. However, P2 proposed a new source of data to P1, proving its fair collaboration. P1 must grant P2 in return by continuing to send data to P2. P1 may also increase the amount of data it sends to P2 to show its gratitude.

- P3 does not hold blocks which interest P1 but P1 can deduce, with the *buffer map*, that P3 is a provider to P2. Even though the information does not let P1 discover a new source of data, P2 collaborates actively and deserves to continue to receive data from P1. P1 can also limit the delivery of data towards P2, notably if the resources of P1 are used by many peers.

- If the announced peers (P3 or P4) are already known by P1, P1 will have the same reaction as the previous case. P2 collaborates actively and P1 continues to send it data. However, the information was not relevant for P1, which can limit the amount of data it sends to P2.

- If P2 informs P1 about P5; P5 has no block of interest for P1, and is in addition, behind P2, P1 estimates P2 has not made enough effort to find new peers. P1 can then sanction P2 by decreasing the amount of data it sends to P2 or by canceling their peering relationship.

Evaluating this kind of mechanism is very challenging. Some do it by implementing the mechanism directly into an open client, while others prefer simulations for trackable large-scale behavior. We are currently implementing this mechanism in a commonly used simulator (PeerSim [14]) to have a fair validation of the proposed mechanism.

5 Conclusion and Future Work

In this work, we proposed a new incentive mechanism for P2P live multimedia streaming systems. The evaluation of peers collaboration is based on the control information exchanged rather than only data. Indeed, this sole criterion is not appropriate to systems for distribution of live multimedia flows because of the nature of continuous media, and their temporal constraints. This mechanism matches our observations of real P2P IPTV systems deployed on the Internet and allows to all peers that cannot reciprocate in the exchange of data to collaborate in the P2P network.

Future work will entail the validation of our novel incentive mechanism and its evaluation, notably the overheads associated with the control information. We must refine the parameters of the mechanism with regard to the reactions of data providers and the quality of peers reported. The mechanism must equally take into account the reputation and confidence in the relationship between peers.

As another improvement for P2P live streaming systems based on the BitTorrent architecture, one can also investigates the algorithm for the orgnanization of data to download (*rarest first*).

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