DECENTRALIZED ECONOMIC MECHANISMS FOR PEER-TO-PEER DATA EXCHANGE

Seminar Paper

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ABSTRACT

This paper presents an extensive comparison of decentralized incentive schemes in peer-to-peer file-sharing systems applied in the most popular existing protocols including BitTorrent, eDonkey2000, Direct Connect, Gnutella, FastTrack, as well as Karma, EigenTrust and Maze. Bearing in mind the large Internet traffic accounted for by these systems, a comparative analysis over a wide range of technical and economic criteria is needed to outline the incentive mechanisms or the specific features responsible for the mitigation of the free-riders' problem. Although most of the systems compared are not in operation anymore, the conclusions drawn are highly relevant for other applications.

We find that properties such as high social visibility, strong performance during periods of high file demand, and the availability of alternatives for any possible bottleneck of a system are common among the more successful peer-to-peer protocols.

Keywords

Peer-to-peer networks, incentive mechanisms, free-riding, comparative analysis

INTRODUCTION

Starting in 2000 with the introduction of the first Gnutella protocol for distributed file sharing, the spread of peer-to-peer networks has soon lead to a state where (depending on the time of the day) 30 to 70% of the entire internet traffic was accounted for by people using applications like BitTorrent. The dynamic nature of IT in general, and p2p technology in particular are responsible for the rise and fall of Internet (and social) phenomena including Napster, Kaaza, and eMule.

A peer-to-peer network is a decentralized system of interacting nodes who simultaneously are providers and consumers of content. According to Crowfcroft,, Gibbens., Kelly and Östring (2003) without central authority, with decentralized (and redundant) storage of resources, peer-to-peer networks are less prone to technical failures and the enlargement of the network by additional nodes would lead to gains in performance and stability.

A main motivation for the research into the field of peer-to-per technologies is their wide range of applications. Generally, there are four fields of use for peer-to-peer networks including information sharing (e.g. for instant messaging like Skype or Yahoo Messenger), search services (e.g. overlay networks like CAN or Chord), resource sharing (e.g. grid middleware such as Globus Toolkit), and filesharing (e.g. BitTorrent). Examples of commercial uses of peer-to-peer systems include video streaming, voice-over-Internet, licensed distribution of games, movies, and software. In addition, there is a growing number of non-commercial uses of peer-to-peer networks, incl. the LionShare[1] project at Pennsylvania State University using the

[1] The Lion Share project

technology for facilitating research, the NASA World Wind program[2] giving access to its data via BitTorent. Nevertheless, the main reason for the wide use of peer-to-peer technologies was, until recently, the illegal transfer of files between Internet users facilitated by now obsolete or legally forbidden systems. The five most popular peer-to-peer protocols were created respectively in 1999 (Direct Connect), 2000 (Gnutella and eDonkey2000), and 2001 (BitTorrent, FastTrack). Most of their clients or their index sites were also created between 2001 and 2003. Despite their wide acceptance all of the latter protocols with the notable exception of BitTorrent ceased to exist due to legal actions against them or against their main clients in the years 2006-2012.

The emergence of Apple's iTunes Store (2003), the launch of one-click hosting services such as Megaupload and RapidShare (2005, 2006), the increasing interest of IT corporations like Google and Amazon in online data storage, the increasing interest in and influence of Netflix and of course the rising Internet bandwidth in the last decade are essential economic and business factors for explanation of the rise and fall of the peer-to-peer networks in question. Despite their unquestionable role these events are not a part of the comparison made in this paper which will concentrate on the microeconomic, psychological and some technical features of the incentive mechanisms of the peer-to-peer networks.

In order to address the question of incentives and successful implementation of mechanisms in a peer-to-peer network, one has to become acquainted with core properties of the environment. The networks consist of a large number of peers, who are usually anonymous and a portion of whom is constantly changing. From an economic point of view, presented by Krishnan, Smith, Ramayya and Telang (2003), one observes a certain asymmetry of interest between the sharing side and the receiving side; private costs are different due to different hardware, personal preferences and bandwidth; the valuations of the services are also varying. Moreover, the environment could be described as unsecure due to malicious attacks by some peers. Important for this paper is the fact that from a game theoretic point of view, it is a rational behaviour for users to download files without any contribution at all. This dominant strategy leads to a situation known as "the tragedy of the commons" (Hardin (1968)) in which a large part of the users are free-riding on the contributions of other altruistic users. This could result in overall performance and content deterioration (Raihan Rahman (2009)).

A widely cited study by Hughes et al. in 2005 estimated the portion of free-riders in the Gnutella network at 85%. Findings of such a scope have been a motivation for a huge number of proposed measures mechanisms to reduce free-riding. However, a large part of them, mostly due to technical reasons such as constrained storage or computation power, remain simply theoretical constructs not directly applied to the most widely used networks. It is therefore of a great interest to compare incentive mechanisms applied in real systems.

The paper is structured as follows: Section 2 presents a literature review concentrating on two different analytical approaches; Section 3 presents a wide set of criteria used for the comparison of peer-to-peer systems; in Section 4 the chosen systems with their respective incentive mechanisms will be described, and in Section 5 a comparison will be made. Finally, the Conclusion and Evaluation will summarize the observations, and suggest possible extensions of the comparative research.

RELATED RESEARCH

The short but prolific[3] history of research in free-riding related to peer-to-peer networks started in 2000 with the finding of Adar and Huberman that above 70% of Gnutella users share no resources at all. The results are confirmed by Hughes et al. (2005), Saroiu et al. (2002), Feldman and Chuang (2005), Yang et al. (2006) and Handurukande et al. (2006) Due to the possibly detrimental effects of free-riding to the performance of the system, technical, economic and psychological measures are taken by peer-to-peer network developers or suggested by scholars.

A systematic overview on the different categories of measures against free-riding is given by Obreiter and Nimis (2005) and Raihan Rahman (2009). They postulate that there exist two main types of counter-measures against free-riding: monetary payment schemes and reciprocity-based schemes. In the latter type users receive a service or resource after having paid with a

[2] World Wind Programme

[3] See appendix 1 for the literature research table

virtual currency. Most of the monetary payment schemes remain simply theoretic concepts because of the still not completely feasible assumptions of easily available payment infrastructures, low cost of service providers, and scalability. Examples for monetary payment schemes are PPay, CPay, Karma and others.

In Reciprocity-Based Schemes or reputation schemes peers are distinguished according to their history of previous interactions with other peers. The three main components of these schemes are: collection of behavioural information about a peer (previous upload-download ratio, sharing of authentic or corrupted files, malicious behaviour etc.), scoring and ranking of the users, and rewarding or punishing them (giving them a place in a waiting queue for a file, increasing their download speed etc.). The reputation schemes are based on either direct, or indirect reciprocity. In the former type, users rely only on information gained through their own interaction with one and the same peer. Information is saved locally. In the latter type services to other peers are also taken into account. Information is saved globally. The main application of direct reciprocity schemes is for long periods of time where two peers would have more opportunities to interact and cooperate. Indirect reciprocity systems seem to find a broader adoption, among other things, because of their higher scalability. However, since they have to rely on third party observations a higher vulnerability to whitewashing an Sybil attacks is present.

Specific mechanisms (Hott and Kremms (2007)) used in real peer-to-peer networks are tit-for-tat (BitTorrent), point mechanisms (Maze), credit-debt mechanisms (Karma) and others. In the next section these will be further described and analyzed. Alternative new incentive schemes include lottery-based (Zghaibeh and Harmantzis (2008)) schemes, quality differentiation approaches and advertisement(Wand, Chow and Golubchik (2011)) availability. While lottery-based schemes present a combination of a payment scheme and a random mechanism to choose peers who would not need to pay, quality differentiation find a broad use in video streaming where users self-select in accordance to their preference for video-quality. The amount of advertisement usually accepted as annoying depends on the altruistic behaviour of a peer or of a subscription plan a customer has chosen. If a peer increases his uploads, it will automatically receive less advertisement at sight.

Another way to create an overview on incentive mechanisms and free-riding in peer-to-peer networks is to use the different analytical approaches as categories: the game theoretic approach and the experimental economics view.

The analytical tools of game theory and mechanism design are the most widely used in the research attempts to find an optimal strategy for motivating peers. The three models most frequently used to model behaviour in peer-to-peer systems are the Prisoner's Dilemma (Golle, Brown, Mitonovy (2001)), the Principal Agent (Courcoubetis and Weber (2006)) model and the *Tragedy of the Commons* (Hardin (1968)) comparison for public goods.

The Prisoner's Dilemma describes a one-shot interaction between players who do not act cooperatively and fail to increase efficiency for them both as a whole. Rationally, all players play selfishly reaching a suboptimal allocation of resources. This game corresponds to the set of peers in a peer-to-peer network who free-ride on the resources of the network and contribute less the socially optimal. As a result the performance of the network in terms of content availability (the public good) and diversity is damaged. "The tragedy of the commons" describes quite accurately the situation. In addition, the principal-agent model studies situations in which tasks are delegated from one person to another. Due to the restricted ability of the principal to observe the behaviour of the agent, the selfish behaviour of the agent might lead to a suboptimal result for the principal. The model seeks a design which will help the principal to deal with the information asymmetry. This model corresponds to the situation of the designer of a peer-to-peer network who seeks high performance for his creation and of the users who seek to gain the maximum advantage from the system. A very thorough and systematic overview on economic incentives in peer-to-peer networks is given by Antoniadis, Courcoubetis and Mason (2004). They develop the argument that a scheme that should be optimal from a game theoretic point of view requires a complete knowledge of the preferences and types of the peers in the network. Out of practical reasons they design suboptimal mechanisms (such as average prices or fixed fees) which require much less information and which, however, converge to the efficiency of the first best mechanisms for a large number of peers. Jaeok Park and Mihaela van der Schaar (2010) go further and compare incentive schemes under the conditions of enforced sharing, repeated interaction, partial cooperation etc. Thus, they are able to replicate a bit more accurately the reality of file-sharing systems.

A different analytical approach based on sociological and psychological aspects is the one of experimental economics. Antoniadis and B. Le Grand (2007) believe that providing social incentives should receive a pivotal role when designing incentive schemes for peer-to-peer networks. They argue that game theoretic mechanisms could neither be technically implemented, nor will have the expected effect on peers since they are based on not completely unrealistic assumptions such as rationality and utility maximization. The authors believe that the new social incentives should evolve around attribute as Identity (picture, profile), sense of community (discussions, common goals), sense of efficacy (feedback, status, specific

privileges). Mannak and Rider (2004) seem to support the thesis of Antoniadis et al. emphasising on features of a network such as convenience (automatic start of an upload process) and social visibility (sharing with friends or finding new friends).

In the sections to follow a comparative approach will be used to analyze already existing peer-to-peer networks and their incentive mechanisms. Technical, economic and social features will be discussed alike in order to exemplify the complexity nature of the topic and to distinguish at least a few attributes that appear to be decisive for the performance of a network.

CRITERIA SET FOR COMPARISON AND EVALUATION

Bottlenecks

Bottlenecks are frequently the single-points-of-failure of any system and require special analytical attention. Relating to peer-to-peer networks bottlenecks might be the place where a technical failure leads to the disruption of the entire system. Usually, they will be under the focus of legal attention in the situation of illegally distributed content.

Reputation and History

As derived earlier one of the main types of incentive construction in peer-to-peer networks are indirect reciprocity schemes or reputation systems. Reputation depends on the record of behaviour of a peer, or simply put his history, which could be divided into three types (Feldman, Chuang (2005)): private history (direct interaction between two peers), shared history (depends on the overall behaviour of a peer towards all other peers with whom it has interacted), and subjective history (an average of the trust values given to a peer by other peers weighted with other peer's own reputation values).

Sharing of partially downloaded files

One rather technical issue that leads to serious differences in sharing performance is the ability of clients to share partially downloaded files. Systems that make it possible are more reliable when traffic is very intensive as in times of peak interests in specific new content. In addition, peers are surely online when downloading some content which means automatically that they will for sure be able to upload if enforced by a specific peer-to-peer protocol. The absence of this feature will for sure lead to higher measured levels of free-riding.

Instant Contribution

Xin, Zhang, Yuanchun, and Gao (2012) place an accent on the ease of incentive introduction. It develops and proves the thesis that instant contribution leads to higher levels of cooperation as is in peer-to-peer live streaming where sharing and downloading takes place simultaneously.

User behavior and requirements

Two criteria introduced by Marti and Molina (2006) addressing functionality and direct incentivizing of peers are reliability and punishment. Reliability is a requirement on the availability of content in the network and a guarantee that certain data will be reachable in various moments of time. Punishment is an ex post method to restrict selfish behaviour.

In a technical sense it could disable malicious peers to spread bad resources or overuse the resources of the system, which will automatically improve its performance. From a psychological point of view, one might expect either learning effects (free-riders or malicious peers changing their behaviour for better), or simply positive responses to the warning of the punishment that will follow case of misbehaviour.

Incentive types

Although it is not always possible to directly compare incentive mechanisms, one could use certain more general features. Standardized features related directly to the practical application of incentives are download speed, quality of content and quantity (Marti, Molina 2006) or maximal volume of downloads allowed. High-level contributors might be awarded with higher download speed. Quality differentiation is widely used in peer-to-peer live streaming services which provide films with different resolutions to different types of customers (depending on either subscription plan, or upload behaviour). The intensity and amount of advertisement (Wang et al. (2011)) as an incentive could also be added to the quality category, since it could reduce the utility of the consumer and stimulate him to reciprocate by uploading instead. Quantity of content for free is an economic discrimination mechanism usually employed by for-profit online service providers who have free and paid subscriptions. Similar schemes have, however, also been in some peer-to-peer protocols as stated by Yang et al. (2008) and Blanc et al. (2005).

Based on the taxonomy of incentivizing mechanisms employed by most researchers into peer-to-peer networks which was presented in Section 2 of this work, one could use the involvement of real money as one feature that will distinguish some systems from others. The traditional and most popular peer-to-peer systems are used to share files that require little cost for the contributing peer to produce and distribute content. With the emergence of systems like PayPal or the virtual currency BitCoin (which became a one billion euro market in the end of March 2013) decentralized or semi-decentralized real money payment mechanisms, which were proposed in the beginning of peer-to-peer network era (Home, Pinkas (2001)), seem more and more applicable. Due to the nature of the systems observed and their historic detachment from real money payments, we will still not use this feature in our analyis.

A number of scientific papers on electronic commerce and electronic payment systems list various features that any secure systems that aims at high-performance could have. While Schmidt and Müller (1999) believe that the most important technological properties of a micropayment mechanism are: security, reliability (availability of the systems), scalability (absence of bottlenecks), and latency (performance in times of high-demand for the service), Putland (1997) et al. stress on features such as confidentiality, authentication, integrity (data should not be modified by any other person than the interacting parties, trust, anonymity of interacting parties, and untraceability. Although all of these characteristics seem highly relevant to systems where the main incentive mechanism is a payment scheme, we will only mention them as appropriate for further comparative research where the accent is on the specific type of protocols. The only feature that we will use without modification in our analysis is latency. There are significant differences in both technical infrastructure, and observed performance in peak times among the systems compared. Therefore, this criterion might play an important role in distinguishing the optimal structure of a peer-to-peer network.

Proneness to attacks

Another important block of factors defining behaviour in peer-to-peer virtual space is the proneness to malicious attacks. The three types of attacks that will be used in the current comparative study are the most frequent ones in peer-to-peer networks: slander attacks, sybil attacks and white-washing (Raihan Rahman (2009)).

Sybil attacks (Douceur (2002)) involve the creating and controlling of a large number of fake identities on a peer-to-peer network. They lead to a large influence of a small number of peers over the reputation or sharing mechanisms of the system. Moreover, it is claimed (Douceur (2002)) that sybil attacks are always possible unless a centralized mechanism is in action or huge resources for coordination and accounting are put in place. Still, there are mechanisms for mitigation of the problem like the one by Rowaihy et al. (2007) which proposes an admission control system based around a hierarchy of cooperative peers. The presence of such mechanisms in the compared systems is expected to improve overall performance.

In white washing (Raihan Rahman(2009)) attacks a free-rider amplifies its selfish behaviour and the strain it can put on a network by constantly leaving and re-connecting to a network under new identities. The peer circumvents the incentive mechanisms and avoids penalties on free-riders. Reputation systems are particularly prone to white-washing attacks which can be explained by both the nature of the indirect reciprocity mechanisms, and the availability of identities the cost for which usually amounts to a few seconds or minutes necessary for creating and activating the new profile. Responses to white washing range from assigning (Friedman and Resnick (2002)) long-term strong identities based on IDs by a central authority to imposing temporary restrictions to all newcomers. The former mechanism would inevitably reduce anonymity and increase centralization creating a single-point-of-failure of the system, while the latter seems unfair and having a relatively large social cost on the system (Friedman and Resnick (2002)). Still, it has been shown that in systems with high levels of free-riding penalizing mechanisms can strongly improve overall performance with limited cost.

There are further threats to system stability. Slander attacks (Velloso1, Rafael (2003)) involve malicious nodes colluding and giving untrue information about a particular node – either hurting the reputation of the node, or gaining unfair advantage for the node. Despite the high relevance of slander attacks for networks that possess reputation systems, they will be left out from the current analysis because most of the networks here are using other incentive mechanisms.

Marti et al. (2006) name a few other security issues including Denial-of-Service attacks. While the adverse impact of such threats is undeniable, their role depends mostly on another criterion that has already been mentioned – the single-point-of-failure (bottleneck). Due to the absence of sufficient technical and empirical research material on the topic, we will refrain from deeper analysis and will not use this criterion.

Social visibility

According to Bretzke and Vassileva (2003) social factors play a major role during a user's decision to share. In their explorative study social visibility factors that motivate users to share are investigated. A confirmation of their findings is given by another paper by (Mannak, Ronald (2004)) From the set of factors which includes social visibility, convenience,

reciprocity, utility, materialistic and legal issues we will use one of them as a criterion for comparison, *Social Visibility,* described as the chance to make new contacts and friendships. Its role turns out to be pivotal in systems like Direct Connect or Maze where real online communities have been built around the file sharing milieu that take care for the sustainment of the network.

Another factor which is of very large relevance for any discussion on peer-to-peer files-haring systems is Legal Issues. The media attention at legal actions against peer-to-peer systems and users led to a more moderate sharing behaviour caused by the fear of getting detected. Due to the specific framework of our comparative research the inclusion of this factor will be rather superfluous because all of the systems have become popular via illegal sharing and because all of them except BitTorrent have been forbidden or restricted by law.

SYSTEMS AND INCENTIVE SCHEMES IN COMPARISON

In this section a set of peer-to-peer file-sharing networks will be compared in respect to their incentive mechanisms for stimulating peers to upload and share content. BitTorrent, Gnutella, DirectConnect, FastTrack and eDonkey are all unstructured networks in which peers are organized in a random graph in flat or hierarchical way. To search for content the techniques of flooding, expanding-ring Time-To-Live (TTL) search or random walk are used (Lua, Crowcroft (2004)). These are all decentralized or semi-centralized networks and employ decentralized economic incentive mechanisms which do not need any concentrated authority for their operation. The main reason behind their choice is their wide public use in the period 2001 – 2008, specifically proven through a statistical research by the company Ipoque, a report by Gavosto et al. (2004) and number of scientific papers incl. Karagianis, Faloutos (2004), Lua, Crowcroft (2004), Karagiannis, Broido (2004)]. In order to make the comparison more general three more networks have been included: EigenTrust, Karma and Maze. EigenTrust is a system used as a benchmark in the category of reputation-based incentive mechanisms. Karma is one of the most widely used decentralized credit-based systems (Vishnumurthy (2003)) and Maze is the first academic research project having a large success in terms of peer numbers (Yang, Chen (2005)).

DIRECT Connect

The Direct Connect network (Subhabrata Sen (2006)) is semi-centralized consisting of peers and dispersed hubs. Peers connect to a local hub and download files directly from other peers. The role of a hub is to enable routing between clients for chat, queries and requests for connections[4]. Similarly to the eMule servers (see below) hubs expose lists of users and the files they share. The network features no global identification scheme. The main principle controlling the distribution of files is based on the availability of free "slots" showing the number of peers allowed to download from another peer. Lastly, the most popular Direct Connect client was DC++.

The basic incentive mechanism of the Direct Connect (Bretzke, Vassileva (2003)) network is a simple minimum contribution rule postulating that every single peer has to share at least 3GB of files to the system.

Gnutella

Gnutella is the first fully decentralized P2P file-sharing system. It had a few new releases to improve its scalability and efficiency. At first, it exercised distributed searches on a flat topology of peers, but in later releases a two-tier overlay structure similar to the one of FastTrack was implemented. Gnutella network nodes are divided in two categories: leaf nodes and ultrapeers, which have higher capacity in terms of bandwidth and reliability and act as proxies for the queries of the other nodes. The structure is very robust to peers entering and leaving the system. The most popular Gnutella clients were the open-source LimeWire and Shareaza (Crowcroft, Lua (2004)) which due to legal actions are not accessible anymore.

The Gnutella network has no underlying incentive mechanism so free-riding remains uninfluenced and unpunished. Download requests are served in a *first-come-first-serve* order (Kulbak, Bickson (2005)).

eDonkey2000

eDonkey2000 (ED2K) is a semi-centralized network operated on loosely connected, separate index-servers run by users. Its two most popular client software programmes are eDonkey2000 and eMule. The eMule client has lists of servers and of shared files on the local systems. As soon as a peer is connected to an eMule server and logs into the network, he receives information on the active servers and available files. There is an upload queue for each of the shared files in an eMule server.

[4] http://dcpp.wordpress.com/2006/03/13/power-person-operator/

New peers are placed at the end of the queue and move gradually until begin downloading the file. Fragments of files may also be downloaded from other eMule peers simultaneously, thus increasing speed (Kulbak, Bickson (2005)).

The core incentive mechanism against free-riding in eDonkey2000 (Yunzhao, Gruenbacher (2012)) is closely connected to its queue-dependent sharing model. There is a credit system which simple rewards altruistic sharing behaviour with a faster advance through the queue for a specific file.

FastTrack

In the semi-centralized network FastTrack nodes are categorized as ordinary nodes and supernodes(Kumar, Ross (2004)), a classification similar to the one of Gnutella. Supernodes have the role of temporary local index servers. For each file an ordinary node shares, the supernode receive certain metadata (file name, file size etc.). In order to find a specific file, an ordinary node send a query with keywords to its parent supernode, who either redirects the message to other supernodes or directly replies with metadata (address of the file) corresponding to the search (Kumar, Ross (2004)). If an ordinary node has enough computing power and large enough bandwidth, it can become a supernode, without the necessity of centralized control. The most popular FastTrack clients were KaZaA as well as Grockster and iMesh which due to legal actions are not accessible anymore.

The basic incentive mechanism of FastTrack (Kumar, Ross (2004)) evolves around the participation level of each peer which measures the upload activity. A higher participation level leads to a higher priority when awaiting a specific download.

BitTorrent

Central to the operation of the BitTorrent network is the interaction of torrent trackers, indexer sites and the particular BitTorrent unchocking incentive mechanism which will be explained later. The tracker acting as a central node assists peers **(**Zghaibeh (2005)**)** who are newly connected to a torrent (file containing meta data on the file to share) to communicate with each other. Moreover, the tracker splits a file into 256 kB parts and distributes them to the peers who themselves may act as seeders and forward the pieces to other peers (Raihan Rahman (2009)). Thus a very high download speed is possible and corrupt file pieces may quickly be re-downloaded from another peer. The indexer sites like Pirate Bay, isohount or suprnova.com act as table of contents of torrent files indicating files at disposable at some peer's computer. They usually do not have any connection to a tracker. Some of the most popular BitTorrent clients are among others BitTorrent (own client), µTorrent and BitCommet.

The basic incentive mechanism (Raihan Rahman (2009)) in BitTorrent is Tit-for-Tat, one of the most popular cooperation strategies in game theory (Axelrod (1984)) and industrial economics. There is a direct high correlation between user's uploading altruistic behaviour and his download bandwidth. Starting with cooperation (unchoking) a peer is unchoked depending on his upload rate – copperation leads to cooperation. As in a typical Tit-fot-Tat game even uncooperative peers are unchoked in the beginning as a way to stimulate their sharing behaviour. In case, a peer remains a free-rider his download bandwidth is restricted dramatically from time to time.

EigenTrust

Unlike the before mentioned networks EigenTrust is only an incentive algorithm not having its own technical infrastructure (Sepandar, Schlosse (2003)). It is a reputation system based on indirect reciprocity using trust values of peers weighted by the reputations of those peers who have interacted with them in the past (Lianz, Yu Pengx, Mao Yangx (2008)). It has a wide range of features that can easily be compared with the incentive schemes of large deployed peer-to-peer networks so the inclusion of this mechanism could only contribute to the thoroughness of the analysis.

KARMA

Karma is an economic currency scheme and similar to EigenTrust has no separate peer-to-peer network (Raihan Rahman (2009)). It evolves around the idea of constant accounting of peer's resource consumption and contribution. Generally, each peer's behaviour is summarized by a single value – karma (Vishnumurthy (2003)). Separate sets of nodes, bank sets, bear the responsibility to keep track of any changes to this value. Karma is highly decentralized, bank sets keep peer's information via Distributed Hash Tables and resource distribution and consumption is made via second-price Vickrey auctions (Vishnumurthy(2003)).

Maze

Maze (Lianz, Yu Pengx, Mao Yangx (2008)) is a peer-to-peer file-sharing system which emerged in an academic research project and possesses features of different (older) peer-to-peer systems. Its incentive mechanism is based on point collection whereby a central server audits the transfers and facilitates redirecting of queries. Periodically, peers up-date the information

of the server for the files they own. A notable feature of the Maze network are the peer lists possessed by each node that contain in a differentiated manner information on different groups with whom the node has interacted.

COMPARISON

Bottlenecks

While the only bottlenecks in the Gnutella and FastTrack networks are the ultra peers/super nodes, Direct Connect is more centralized relying on its (decentralized) hubs which are central servers where peers connect. The weakly interconnected servers of the eDonkey2000 network are run by the community and contain only information about the peers and the files they share. In the case of BitTorrent one relies on central trackers hosting the torrent files, keeping track of the peers possessing the specific files to share and helping them connect for uploading and downloading. An important single point of failure for BitTorrent are the indexing websites (e.g. The Pirate Bay, isohunt, suprnova.org) that are very prone to legal actions due to the high amount of copyrighted content distributed.

Maze has e central server that takes care of the accounting concerned with transfers and personal scores; since it relies on a shared history reputation mechanism (see below) some scalability issuesdue to computation strain on the system might occur. Karma has no centralized authority to do the auditing since reliable peers from the network (the bank-sets) are dedicated to the process. This strategy ensures fault tolerance, security enhancing redundancy of information and general tolerance to malicious attacks. Lastly, the EigenTrust model suggests relying on other peers to store the weighted trust values of a user so that no manipulation by the user himself can take place. Thus high decentralization is secured.

Sharing of partially downloaded files

Like Gnutella (with the exception of its client LimeWire) and FastTrack, Direct Connect and Maze do not support sharing of partial files. eDonkey2000 via its Multisource File Transmission Protocol and BitTorrent possess the feature so a peer can start uploading before having downloaded the entire file. The feature is not applicable to Karma and EigenTrust.

Instant Contribution

Due to the absence of direct incentive mechanisms in Direct Connect other than under certain circumstances a required minimum of uploaded files, there is no accent on instant contribution after a file has been downloaded. FastTrack, on the contrary, has an incentive scheme based on a participation rate (e.g. in KaZaa). Still, it relies on a long-term interaction with the system meaning again a missing emphasis on current actions. Similarly, the eDonkey2000 protocol (represented by its main client eMule) makes the queue ranks for a files dependant on previous upload-download behaviour. Due to the nature of the reputation or point mechanisms in Maze and EigenTrust long-run behaviour is more important. In contrast, BitTorrent's algorithm relies completely on the instant contribution of downloading peers. Peers with high upload bandwidth capacity and peers who actively share (even though they are still leachers of a file) are preferred in the process file distribution. The often mentioned "optimistic unchoking" is a direct reciprocity mechanism stimulating peers to start uploading the partially downloaded file in order to get a higher speed for the remaining part of the file. Finally, Karma stimulates users to keep a balanced account of uploads and downloads which indirectly leads to a strong accent on instant contribution in any situation because peers might frequently find themselves with insufficient amount of karma to pay for a file.

Reliability

Historically speaking, FastTrack and Gnutella were highly reliable and usually available due to their hierarchical structure with easily replaceable supernodes/superusers. In the case of eDonkey the availability of free index servers determines the reliability of the entire network. As soon as a critical number of peers served by a server is reached, another server has to be contacted. Due to the multiple dependencies in the BitTorrent chain of interactions, reliability of the system and so the availability of files is lower than in the before-mentioned systems. Index sites, although they are not a true component of the BitTorrent network, and trackers are susceptible to legal attacks and technical failures which might lead to lower general performance. Due to the more centralized nature of Maze and the possibility to easily request unavailable files on the private forums of the network, the system is highly reliable. The feature is not applicable to EigenTrust and Karma.

Latency/Flash crowd effect and multisource-downloading

With the notable exception of Gnutella all other peer-to-peer networks in our set support multisource-downloading. In the event of a flash crowd effect systems allowing sharing of partially downloaded files such as BitTorrent an eDonkey have a

strong advantage. The high demand for downloads is quickly answered by the BitTorrent system which quickly creates new seeds. The advantage of FastTrack and Gnutella, on the other hand, is their dynamic nature which makes it possible to appoint new supernodes/superusers if the high demand requires it.

Proneness to attacks (Sybil and white washing)

Generally, peers in Gnutella, BitTorrent and eDonkey2000 cannot gain anything from creating additional fake accounts, so typical whitewashing or Sybil attacks are irrelevant. In FastTrack the problem of an own low participation level could be solved by creating a new account which would definitely reduce the efficiency of the incentive mechanism. In Direct Connect free-riders or malicious peers providing fake accounts could be removed from a particular hub but still the registration of a new identity could hardly be tracked, so whitewashing attacks are imaginable. EigenTrust does not assign any initial credits to new comers what generally reduces the incentive for whitewashing. In the case of low reputation due to a high number of corrupt files shared in the system creating new accounts will, however, be rational. In Robust Incentives via Multilevel Tit for tat Qiao Lianz, Yu Peng et al. prove that EigenTrust is robust to malicious colluders in Sybil attacks during an experiment on the Maze network. Under the original policies of Maze both Sybil attacks, and whitewashing have been observed. In order to increase one's own points, fake accounts are created and mutual exchange is brought about. Since all new peers receive initial points in the system, whitewashing attacks might also be profitable for uncooperative peers. Likewise, new peers in Karma receive an initial amount of karma which also might encourage white washing. There is also no mechanism against more complex Sybil attacks.

Reputation and History

As previously stated, the Gnutella and Direct Connect networks have no incentive mechanisms related to reputation or previous behaviour. FastTrack falls in the category of shared history with participation levels depending on a peers' overall upload-download history. The credit system in the eDonkey network is local, so it falls in the private history category. The tit-for-tat mechanism of BitTorrent places network in the private history category, too. EigenTrust, on the other hand, is a benchmark case for subjective history and transitive trust: peers have high opinions of peers from whom they have received authentic files and therefore would value their opinion about other users higher. The next incentive scheme, Karma, is based on a virtual currency but it could indirectly be understood as a (FastTrack-like) shared history. Lastly, Maze's incentive policy falls, unsurprisingly, in the shared history category with values stored at the central server.

Pollution

Since in Gnutella and FastTrack there is no way to avoid corrupted pieces of a file getting downloaded during the download process, one frequently has to re-download entire files. These networks included lots of fake files, partially, due to the actions of owners of illegally distributed copyrighted data. The community-run hubs of Direct Connect prevented its networks from becoming overwhelmed with corrupt files, but the incomplete hash algorithm, still, lead like in Gnutella and FastTrack to failed downloads. In eDonkey and BitTorrent file integrity hash checks take place simultaneously with the download of the file. Since the information chunks are quite small (256 kB in BitTorrent), only small pieces of the file should be re-downloaded if corrupt. Both Karma, and EigenTrust protect against compromised files via their reputation, or respectively, currency mechanisms. In Karma a peer would not be paid with karma-credits if he shares an unauthentic file; in EigenTrust a malicious peer would face a stark decrease of his reputation.

Punishment type

Whereas eDonkey, FastTrack and Gnutella approach free-riding peers with no punishment (except for lower speed of a download due to the way of working of their incentive mechanisms), the Direct Connect protocol allows the decentralized hubs explicitly to redirect peers to other hubs or to even remove them completely from the system. These actions might also be pointed at free-riders. The only punishment in the BitTorrent protocol is the choking of the download of a passive peer. Karma simply forbids users who do not possess enough credit points (karma) to consume further files unless they themselves act altruistically. The way Maze punishes unaltruistic behaviour is by throttling download speed at a lower rate of 300 kbps until a peer starts uploading content. In EigenTrust there is no punishment mechanism.

Incentive type (download speed, quality of content and quantity)

In the current sample of incentive mechanisms and peer-to-peer networks variety of incentive types is rather moderate. FastTrack, eDonkey2000, BitTorrent, and Maze build their incentives around downloading speed. EigenTrust, similarly, suggests greater bandwidth and higher connectivity to other reputable peers as a reward. The rudimentary incentive mechanism of Direct Connect is quantity (minimal required amount of uploads) and in Karma peers are forced to keep their contribution and consumption in equilibrium.

Social Visibility

According to Bretzke and Vassileva (2003) Direct Connect owed its success and low levels of free-riding to its "strong community". Hubs are run by intrinsically motivated peers and often have special fields of interest who make the aggregation of like-minded users easier. Thus efficiency levels are increased. Gnutella, and more specifically its clients BearShare and LimeWire support the Browse-Host extension which allows a peer to browse through the list of files to share of another peer. Users can gain insights into new materials and even create connections to other peers. Similarly, the message and friend system of eDonkey2000's client eMule makes it possible to sustain virtual friendships which generally lead to higher overall performance of the network. In contrast, a negative example of a weaker community (McGuire, Johnson (2007)) is given by FastTrack's KaZaA which experienced a massive outflow of users after continual attempts of the developers of the client to increase revenue by advertisement placement in 2006. BitTorrent itself has no integrated ways of social interaction between users, so it has to completely rely on the online communities built around torrent index sites. Conversely, Maze has started as a research community project and owes its success to policies such as "friend-list" of peers or "neighbourhood-lists" which contain trusted or, respectively, physically close peers. Social status in the community, measured by online forum seniority and highly altruistic behaviour related to file-sharing, is highly appreciated.

EVALUATION AND CONCLUSION

After the thorough comparison of various technical and purely incentive-oriented features, one could draw a few general conclusions about efficient peer-to-peer file-sharing systems. Both due to the slightly interpretative nature of some deductions (e.g. high vs. low reliability of a system), and due to the relevance of unobserved factors such as legal issues, one should not aim at determining the best network or the most effective incentive mechanism. Despite some shortcomings to other networks BitTorrent is the most widely used peer-to-peer file-sharing system in 2007 (see table below) with a share of about 65% of the traffic volume. What is more, in 2012 the share of BitTorrent to almost 80%[5]. However, one clearly observes that the adoption of a specific protocol and its popularity also depend on the particular geographic location, or put in another way, its market. Thus the success of a file-sharing system (approximated with its popularity in terms of traffic volume) does not entirely depend on its features and incentive mechanisms, but also on legal aspects and business models.

Protocol	Germany	Eastern Europe	Southern Europe	Middle East	Australia
BitTorrent	66.70%	65.71%	40.09%	56.21%	73.40%
eDonkey	28.59%	2.66%	57.05%	38.51%	13.58%
Gnutella	3.72%	1.90%	2.23%	3.10%	8.84%
DirectConnect	0.52%	28.72%	0.18%	0.39%	0.28%
Other	0.47%	1.01%	0.45%	1.97%	3.90%

Traffic volume distribution for the most popular P2P protocols in five different regions, ipoque study 2007

Still, the overall findings of the comparative analysis are crucial for devising a set of general performance requirements towards a peer-to-peer file-sharing system and its incentive mechanism. Firstly, starting with the technical criteria, one observes that both networks that are very decentralized such as Gnutella and FastTrack, and systems as BitTorrent and eDonkey2000 that have specific bottlenecks (tracker, servers) can be successful. A possible explanation might lie in the possibility to easily find a replacement for any bottleneck including alternative index sites or trackers in the case of BitTorrent or alternative local servers for eDonkey2000.

[5] Sandvine Global Internet Phenomena Report 2012 2H

Another combination of features seems to be directly related to efficiency and user satisfaction: sharing of partially downloaded files, latency and multisource downloading. Systems that have these properties perform extremely high during flash crowds when strongly demanded and popular files are released online. Examples for such files are popular songs, new movies and computer games that can lead to extreme consumer hypes. Customers who would prefer avoiding the payment for the specific file but still would like to enjoy the data as soon as possible could easily opt for a file-sharing system that could give them the fastest download. BitTorrent is the system that has the best performance in flash crowd due to both algorithmic reasons, and successful application of its tit-for-tat free-riding mechanism.

Furthermore, the analysis of the incentive type choice in all networks reveals an attempt at simplicity. All eight incentive schemes use either speed of download, or quantity as a way to stimulate cooperation. With the exception of Direct Connect all other networks refrain from using any severe punishment different from the ones directly related to the underlying incentive mechanisms. Not removing free-riders but leaving the opportunity to influence them seems a common design choice of all network developers.

Another feature, accent on instant contribution, correlates strikingly with the lifetime of files in a network and with the behaviour of free-riders. While other networks work towards the establishment of a long-term cooperation based on participation rate or credit systems, BitTorrent motivates only short-term cooperation. To quickly receive a file, a peer gladly uploads parts of the downloaded file simultaneously. Seeding behaviour in the long-run is, however, scarce which corresponds to a high number of free-riders. A possible recommendation in this specific situation is the consideration of a combined incentive mechanism built around BitTorrent's tit-for-tat but also bearing some features of FastTracks or Karmas long-term oriented credit systems. Only so peers would have an incentive to behave cooperatively most of the time.

Lastly, social visibility emerges as a central factor for the regular performance of a network. The strong communities around Maze and DirectConnect increase in a natural way the inherent generosity of peers this making it possible to avoid the tragedy of the commons. Taking the cost of the hub/server maintenance peers do not act rationally as game theory would predict. Still, overall performance is improved. Developing a supporter base of peers might be costly and might have a negative effect on scalability of a system, but it could significantly reduce the consequences of the free-rider problem.

Towards the end of the paper there are several recommendations for further research that could be taken into consideration. Firstly, a larger sample of peer-to-peer networks and incentive mechanisms could be taken for the comparative analysis. Assuming the availability of scientific material, the inclusion of older peer-to-peer networks such as Ares or Overnet might create a complete overview of systems responsible for the popularization of the model. Moreover, the addition of theoretic peer-to-peer incentive schemes which rely explicitly on mechanism design such as Credence, BitTyrant or Samsara, or on payment-based schemes such as PPay or CPay could point more and more in the direction of removing the flaws of existing networks.

A second major recommendation for further research is the statistical analysis of the findings of this or a more detailed comparative research. Although quantifying some features of the incentive mechanisms could hardly be completely objective, if some space for interpretation is allowed, one can produce a data set of a number of observed systems which are compared according to several dummy (0-1) features. Based on the covariance matrix of the observations, a biplot presenting the principle components of the covariance matrix could quantitatively show clusters of networks. In our case, networks like Gnutella and FastTrack are expected to be very close to one another in such a statistical representation.

In conclusion, although peer-to-peer network traffic dramatically declined in the last few years, it increased the share of legal content distributed via its channels[6]. Most of the file-sharing systems have been closed after legal actions and not due to the consequences of free-riding and inefficiency. The last large remaining distributed file-sharing system, BitTorrent, shows a clear move towards peer-to-peer live streaming responding rather to industrial economic and business issues than to microeconomic and game theoretic ones[7]. Nevertheless, the potential of distributed peer-to-peer networks, which has been proven between 2000-2010, and the scientific work dedicated to the analysis of both technical, and economic aspects can find broad applications both in information systems, and in social or economics networks.

[6] Sandvine Global Internet Phenomena Report 2012 2H

[7] http://thenextweb.com/insider/2013/03/12/BitTorrent-launches-live-p2p-streaming-protocol-in-open-beta-cuts-costs-for-anyone-looking-to-broadcast/

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