Sociable P2P: using social information in P2P systems

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ABSTRACT

This paper examines the role for social information in peer-to-peer content sharing and distribution systems. Much work in P2P research has taken, as fundamental assumptions, that participants in a P2P network consist of largely anonymous and self-interested agents. As such, cooperation and public good problems arise when rational peers prefer to free-ride rather than contribute; various incentive mechanisms are required to prevent system collapse due to mass defection. With the introduction of social information, however, it may be possible to complement purely rational mechanisms with a priori social relations. In reframing P2P agents as sociable peers, some aspects of the anonymity and rationality assumptions may be weakened or modified. The paper analyzes some current applications of social information to P2P systems, and assesses the favorable and unfavorable implications of social-information aware P2P agents and networks.

Categories and Subject Descriptors

C.2.4 [**Computer-Communication Networks**]: Distributed Systems

General Terms

Design

Keywords

P2P, social networks, trust, incentives, survey, analysis

1. INTRODUCTION

Since the rise of Napster in 1999, ad-hoc content sharing and distribution has remained one (if not *the*) "killer app" of peer-to-peer (P2P) networking technologies. “How do I find the things I want?" and “How can I get the things that I want from the people who have them?" have been two of the fundamental problems in this domain, and are the main questions that networking researchers and P2P network designers have hence strived to answer.

The solution space to these questions has evolved significantly over the last 8 years. In particular, the question of motivating cooperation on a P2P network has been studied extensively from various perspectives. Analyses based on game-theoretic frameworks have been especially insightful. Making the assumption that each participant is an independent, strategic, rational agent engaging in iterated games, the game theory perspective predicts a “tragedy of the commons" effect, with significant free-riding that is likely to degrade overall system performance [16, 24]. The literature presents various incentive mechanisms to encourage cooperation, such as reputation, bartering, or currency-based systems, though each with their own advantages and disadvantages [4].

In this paper, I examine the value of using social information as a complementary solution to the aforementioned techniques. Using social networks to find information or encourage cooperation is an intuitive approach that has close metaphors in human-to-human interactions. By reducing the opacity between peers, social information may potentially provide additional incentives for cooperation, reduce the tendency to free-ride, and create additional dimensions for collaborative experiences. I review the context and incentives for cooperation in P2P networks, examine existing work that apply social information to P2P systems, and assess the potential implications of sociable P2P.

2. CONTEXT

A peer-to-peer network can be thought of as a type of overlay network, operating at the application layer of the network stack. Built atop of the conventional Internet routing architecture, a P2P network provides a set of logical routing links independent of the underlying physical network links. The network is decentralized, in that peers contribute content and share them with other peers. Peers may also function as logical routers, forwarding network requests to other peers.

There are a number of advantages in such an architecture. By distributing the task of content storage and distribution among a set of peers, a P2P system tend to be more scalable and damage resistance than conventional client-server models. However, decentralization in the typical P2P network also implies anarchy in the network - that is, there is no central authority dictating terms of participation to each peer. This anarchy gives rise to a class of cooperation problems, in which a peer is rationally motivated to contribute as little as possible while consuming as much as it desires. Such free-riding behavior has been empirically observed on the Gnutella P2P network, accounting for 70 to 80 percent of all users [1, 17].

2.1 The Prisoner’s Dilemma

One means of examining the cooperation and free-riding problems in P2P networks is to frame them in game theoretic terms. P2P sharing resembles the iterated Prisoner’s Dilemma (PD) game [3], and has often been modeled as such with various modifications [29, 12]. The game consists of two players, whose choices are mirrored; they may either cooperate with the other, or to defect on the other.

In essence, there exists a tension between cooperating (that is, contributing content) which benefits the overall utility of the network, or defecting (that is, consuming but not contributing content), which serves only individual utility. The reward payoff for mutual cooperation would maximize overall utility, as both peers would obtain the content that they seek. The temptation payoff - that is, the ego peer defects while the partner peer cooperates - provides more individual reward, as the ego peer obtains the content without expending any scarce resources. Even the punishment payoff - both peers not getting the content at all - tends to be preferable to the sucker scenario where the ego expended resources to provide content but received nothing in return. It is easy to see that agents would prefer to defect, under these conditions, regardless of its partner's strategy.

The aforementioned analyses assume that agents are largely *rational* and *strategic*. That is, each agent wishes to maximize utility for itself, while conserving its own bandwidth, CPU power, and other scarce resources; moreover, it would manipulate its own behavior and "game the system" to obtain this maximal payoff. As researchers note [31, 11], this is in contrast to the traditional *obedience* assumption - that agents would tend to follow the designed protocol as intended by the architects of the network. The rational model better predicts free-riding as empirically observed in [1].

2.2 Accounting for rationality

Given that the predicted free-riding problems have arisen in deployed P2P systems, solutions that account for agent rationality have been proposed. These tend to involve some type of incentive mechanism, to tempt or coerce cooperative behavior from rational agents.

One such class of solutions involves the introduction of reciprocity, or creating a "shadow of the future" for peers. In Axelrod's [3] formulation of the iterated Prisoner's Dilemma, the "Tit-for-Tat" (TFT) strategy emerged to be an effective general-purpose approach to dealing with free-riders. Its concept is quite simple: *cooperate unless betrayed, retaliate but forgive*. Agents would cooperate with other well-behaved agents, but retaliate against free-riders by refusing content exchanges with them until they begin cooperating. The popular BitTorrent protocol specifies a variant of this strategy, which achieves good results in curbing free-riding [10]. However, recent studies show that the BitTorrent variant of TFT remains vulnerable to strategic manipulation, such that free-riders may achieve nearly equal performance to contributors [19, 27].

Another approach involves indirect, reputation-based systems. In essence, these approaches tend to provide a distributed means of computing reputation of a peer [15, 20]. The Eigentrust algorithm [20], for example, builds a "trust" score for a given peer, using reported upload behavior from other peer nodes. Thus, agents can provide differentiated levels of service to highly ranked or "trusted" peers, using indirect information, and reject "untrusted" or free-riding peers. However, these classes of solutions tend to transfer the problem, from trust in peers to trust in reputation reports from other peers. If a "malicious collective" of peers collude to falsify reputation information, praising or slandering a particular peer, then the reputation thus calculated could be misleading.

Other classes of solutions involve exchanges of virtual currency [32, 13]. In these cases, peers are "paid" in currency for their cooperation and contributions, with which they can obtain further services from other peers. As noted in [4], such designs must balance between endowing "poor" newcomers so as to allow them to join the network, and holding off whitewashing attacks from strategic peers who might continually change identities to collect such endowments.

3. SOCIABLE PEERS

Sociable peers are P2P clients that access and keep track of social information - external information about its associations with other peers. These can include concepts of *friendship*, *common interests*, *areas of expertise*, etc. and can be exchanged between peers. Whether these relationships are formed by *a priori* association between the users of P2P clients, or via implicit assessments at the client-level, determine what types of social information are available.

Rather than the modern instantiation of the *homo economicus*, as posited by fully rational perspectives on P2P, the sociable peer may have non-rational behaviors and interests. With friendship, it may have access to a social network, a yet higher-level social overlay atop the technological overlay of P2P networks.

3.1 People and clients

P2P clients fundamentally act on behalf of users, and as *homo sapiens*, human users may deviate from the baseline of utility maximization. Humans can potentially be motivated by other interests, such as kinship, friendship, personal likes and dislikes, social recognition, or other non-utilitarian goals. Intuitively, we tend to find ourselves more willing to trust or help friends or family. The recommendation of a friend carry more weight that the same from a stranger, whether it be for finding a good restaurant or hiring someone for a job.

If social information can be overlaid atop a P2P network, it may be possible to weaken the rationality and anonymity assumptions in certain cases. By revealing some properties of the humans behind the agents, it may also be possible to create additional mechanisms to improve upon purely rational incentive models. There are, of course, consequences to weakened rationality and anonymity as well, and they must be considered in turn.

3.2 Social motivations for cooperation

There are many possible motivations for limited-rational behavior in cooperation and public-good type scenarios. For example, Andreoni [2] notes the "warm glow" effect of altruism on participants, thus introducing private utility while contributing to a public good. However, supposing that social information is known, other mechanisms are possible.

There is evidence to suggest that people are more generous toward friends [3, 23] and those closest to them within their social networks [6]. This is linked with the general idea of reciprocity and the "shadow of the future". With anticipated future interactions, which are usually very likely with family, friends, and close associates, it is usually within the interest of the individual to cooperate, if only to preserve social ties. Further, a seemingly altruistic move may simply signal an expectation of reciprocation in the near future. Literature in gift-giving [8] explores this extensively, and I leave the topic of P2P information sharing as gift-exchange to more capable authors of that field.

Prior associations may also the general level of uncertainty in the exchange; knowing certain properties about the other person helps to form expectations of future behavior. This is a generalization of traditional P2P reputation-tracking, as it can inject external data beyond purely the history of prior data-exchange.

There may also exist social norms for cooperation, which may be enforced against deviant individuals. Membership in a social in-group carries the implicit threat of removal if norms are not followed, and should these threats be credible, there exists an incentive to conform to the rules.

Mannak et al [25] conducted an exploratory study of sharing in P2P systems, and within their six categories of motivations, social visibility also emerged as a strong factor. The idea that efficacy - the sense that one person's actions “made a difference", social validation, and public recognition can be a motivating factor for public goods provision is not new to the literature [21]. Thus, there may be similar effects in P2P cooperation as well, if these mechanisms are made available.

3.3 Sociable P2P systems

There has been some work in designing, implementing, and measuring sociable P2P architectures at varying levels of completeness and complexity. Some implement a full social network overlay for a P2P protocol, allowing sociable clients to draw upon human-to-human relations as metadata. Others make use of social proximity and common interests to improve routing performance. Others simply use social information and motivations as an additional layer of incentives for promoting better user behavior. I review four particular examples of sociable P2P: Tribler, F2F networks, Socialized.Net, and Comtella.

3.3.1 Tribler

Tribler [18, 22] is a cross-platform, BitTorrent-based P2P network that maintains a social overlay of its participant nodes. The Tribler network attempts to use social information to address what its designers believe to be the five "grand challenges" of P2P research - decentralization, availability, integrity, incentives, and network transparency [18]. The result is a sociable P2P network that provides some interesting features and incentives, beyond what is usually available.

As a first step, Tribler de-anonymizes peers by introducing a *PermID*, a public-key cryptography based identity created upon first use. To bootstrap a social network, it identifies contacts and friends of users, either by manual exchanges of PermIDs, or by importation and invitation based on the user's MSN or Gmail contact lists. Once the social network is in place, Tribler can use this information to provide advanced functionality.

One particular Tribler feature is Buddycast, a content discovery and recommendation engine. Peers on Tribler can express preference for content; they implicitly do so by downloading content (e.g. things that a user recently downloaded is a proxy for things that he prefers), and explicitly do so by marking content as "Files I Like". These preferences are exchanged via an epidemic model (with some optimizations) with the social network, and (with a small probability) with other random peers. In this fashion, "taste buddies" or peers with similar content are identified, and a collaborative filtering scheme can be applied to recommend other content to the user based on this data.

Another feature of the Tribler network is cooperative downloading. In this case, friends donate their bandwidth to a single peer to help it download faster. These friends are not necessarily interested in the content itself. However, each friend-peer, or *helper*, collaborates with others to obtain some pieces of the desired content. In turn, they transfer them to the original peer who *is* interested in the content, with the social expectation that this altruistic donation would be reciprocated at some future time with some other content. This model is reminiscent of the Southampton strategy, the winner of a 2004 iterated Prisoner's Dilemma tournament, in which colluding "servant" agents attempted to detect and donate points to a pre-set "master" agent [30]. In Tribler's case, empirical measurements show an approximate 3.5-time speed up in download time compared to a classical BitTorrent agent, with an optimal number of 8 helpers in the swarm [14].

Tribler trades anonymity and bandwidth in exchange for more relevant searches, recommendation features, and faster downloads. The nature of this tradeoff may be appropriate for certain use cases, but perhaps less so for others. Cooperative download, in particular, could generate significantly more traffic than conventional P2P downloads.

Tribler has been released to the public, and is being used in P2P multimedia distribution.[1]

3.3.2 F2F networks / darknets

Similar to Tribler, so-called F2F networks such as WASTE [2] or Turtle [28] makes use of existing social relationships as an overlay for network connections. However, designers of these systems are interested in security and privacy as top design goals. Local anonymity is weakened; each peer is aware of the identities of their immediate neighboring peers and can trust them as friends. At the same time, global anonymity is preserved; peers beyond the immediate circle would have great difficulty detecting traffic flows or identities.

The typical interaction with a F2F network such as WASTE begins with the exchange of public keys and network addresses with a friend. These keys are secure identities that enable connections between one peer node and another. Peers that do not know each other (via their public keys) would not be able to communicate.

Once an immediate circle of links are established, peers can query for content exchange messages, upload or download files, and perform other types of P2P content distribution activities. Each peer only interacts with its immediate neighbors. If messages are routed toward a non-connected peer, the identity of the originating peer is not revealed; the second-degree node, thus, cannot tell whether if an immediate friend made the request, or if he simply routed a request on behalf of someone else. Data is encrypted from one link to the next, as opposed to end-to-end encryption; presumably, one's immediate friends are sufficiently trustworthy.

F2F networks rely on the "small-world" phenomena [26] - that any peer can reach any other peer within some relatively small number of hops over social network links. As with Tribler, analysis of social network topologies as Friendster seem to suggest that this assumption may be somewhat reasonable, given sufficient adoption of the technology [18].

3.3.3 The Socialized.Net

Unlike the previous systems, The Socialized.Net (TSN) [5] attempts to detect "social" relations at the P2P agent level, and uses the network address as a cue for location-based services.

TSN runs as a set of applications implemented atop a TSN daemon, each supplying a set of content resources and metadata de-

[1] An open-source client is available from `http://tribler.org`

[2] http://waste.sourceforge.net

scriptions of those resources. The TSN daemon broadcasts to the local network (ad-hoc wireless network or LAN) in order to detect other TSN daemons. When another daemon is found, the two TSN agents contact each other and make introductions, exchange application resource descriptions, and gossip about other clients that they have encountered. Gossip messages include content interests, introductions on behalf of other nodes (that is, friends of friends), reputation information about other TSN nodes, and other such data. Likewise, searches are sent by flooding to known TSN nodes, but only for nodes that have similar content interests.

Several applications are possible on a TSN platform. The TSN prototype deployed a plug-in for the Azureus client, which allowed TSN users to obtain search for and download torrents directly within Azureus - without the use of centralized torrent indexes such as Mininova. Another application allowed laptop computers to exchange browser bookmarks when their owners physically meet other (and connect to the same LAN), such as at a conference. Once introduced, these daemons might be able talk to other even after the conference is over, thus continuing information exchanges on behalf of their owners.

The implication of such a design is that nodes must "physically" meet (or come to reside on the same network) to become aware of each other. The author of TSN proposes a set of centralized index servers, or "well-known" super nodes, that may be used to introduce far-away nodes to each other. On the other hand, local network proximity allows some potentially useful (if possibly inaccurate) location-based assumptions, which the author relies (perhaps unwisely) on for a number of purposes.

3.3.4 Comtella

Comtella [7, 9] is a modification of the Gnutella client to provide social incentives for cooperation. Comtella attempts to motivate good behavior and punish bad behavior on part of the P2P user, by modeling behavior based on a history of user actions. Using this model, the program then attempts to reward cooperation through promoting social visibility and peer recognition of good behavior, keeping track of friendships and relations with other peers, and providing quality-of-service (QoS) differentiation for friends or highly cooperative peers.

Comtella rewards five types of "good" behavior: staying online, staying logged in, sharing downloaded content, introducing new content, and annotating content with metadata. Similarly, user cooperativeness is modeled for altruism (unilateral good behavior), reciprocal giving (tit-for-tat good behavior), or selfish (bad behavior). User relationships are established via a history of past interactions or shared interests, and weighted by cooperativeness and the "balance" of data volume exchanged between the peers.

Good behaviors are rewarded in concrete means by priority in data transfer, and by skipping time-to-live decrement when routing queries from that node. There also exist community-wide member status (gold, silver, bronze) thresholds and visualizations that publicize contribution rankings, both of which serve to reward best-behaving users. Good behavior also triggers positive reinforcement messages in the program UI. Conversely, bad behavior triggers negative reinforcement text and visualizations, and lack of recognition.

Comtella's model differs from the previous systems slightly, as it draws mostly upon ongoing histories of social interactions and behaviors, rather than existing human relationships or machine relationships. Further, it uses social information as motivational mechanisms, attempting to induce user altruism and cooperative behavior through community awareness and accountability. Empirical evaluations [9] indicate that contributions did increase significantly, and that a majority of users checked their community status and contribution levels at least weekly. Interestingly, the overall quality of contributions decreased, as users apparently considered community status and recognition-seeking goals in of themselves, at the expense of quality.

4. OPEN ISSUES

Current work in sociable P2P suggests that making use of social information can improve upon traditional P2P approaches. However, several challenges are already apparent. Strong notions of identity are difficult to maintain in a decentralized context, and there are privacy implications of attaching identities to P2P networks. Further, the process of mapping human social networks and relationships to P2P networks is not necessarily straightforward. To compound the problem, the segmentation of a P2P topology into socially constituted cliques of most-favored clients may carry efficiency implications.

4.1 Identity and privacy

The problem of identity in P2P networks has been a recognized issue. Cheap pseudonyms have provided for various means of attacks against many P2P incentive schemes, such as whitewashing or Sybil attacks. The use of social information turns the problem on its head: how to maintain strong identities in a decentralized, anarchistic environment, and how to detect spoofed identities. In essence, how does one identify friend from stranger (or indeed, foe)?

Tribler and F2F networks implement public-key based identity exchanges. Yet the problem then becomes similar to a classical issue with public keys: how does one know that this public key is from a friend? One might presume the existence of a trusted external channel: a physical exchange of keys, a telephone call, etc. Alternatively, it may be possible to adopt a PGP-style web of trust scheme, whereby a third party guarantees the information.

On the other side of the spectrum, strong identities often clash with user expectations of privacy. In the P2P context, this may be especially problematic given the types of content being exchanged and the legal quagmire surrounding P2P filesharing. Anonymity may in fact be a design objective for P2P systems, but the tradeoff made affects the usefulness of social information. If all agents are entirely anonymous to each other, then there can be no means of effective social information exchange.

4.2 The problem of social networks

While social information is not necessarily social network information, the two concepts are somewhat entwined. The concept of "friendship" and "trust" are also easily conflated - there is a presumption that friendship implies trust.

However, the human social network is not necessarily an effective P2P network. Friends may be physical distant; preferring a friend over a closer stranger may reduce the efficiency of the network. Friends may be sparse for a given P2P transaction; many people do not use P2P programs, and those who do must be online and either interested in the same content, or must be willing to make altruistic bandwidth donations.

Further, trust in one social context may not be portable to another. For example, I might trust a friend to work together on a project, but not necessarily count on him to pay back a $5 loan. Social relationships are rather complex, far more so than a weighted edge on a network graph.

This also raises an interesting question of "friendship" in context of P2P file exchange. As sociable P2P systems keep persistent notions of identity, and given that people congregate within related interest areas for content, would users begin to notice each other as they jump in and out of content swarms? If the system design deliberately encouraged such behavior, would frequent P2P cooperators notice each other and come together to create ad-hoc relations? Much as the phrase "Facebook friends" implies weak social ties in context of social-networking sites, is it possible to make "BitTorrent friends"? TSN attempted to do this at the agent-level, but some value is missing when the humans themselves are not considered.

4.3 Cliques

Social networks can form cliques, or closely knitted circles of friendship with few external links. Peers of a clique may share some similar interests, and may provide QoS differentiation that favor those within the group and discriminate against those outside it.

It is relatively unclear whether a world of sociable peers would form a topology consisting largely of cliques, and whether these cliques would cause a general decline in network efficiency. Certainly in an ideal state, all peers should exchange data with all other peers when necessary. It remains to be seen whether a topology of cliques would outperform or underperform a traditional open topology that may be riddled with free-riders.

5. CONCLUSIONS

In this paper, I have presented the concept of sociable P2P architectures. By using social information to complement purely rational incentive mechanisms and routing structures, it may be possible to improve the performance of P2P systems and user experiences in P2P clients. I reviewed Tribler, F2F networks, The Socialized.Net, and Comtella, each of which explored some aspects of sociable P2P systems. Finally, I presented some open questions that yet remain.

The techniques and strategies of sociable P2P appear to have significant promise. Further theoretical investigation and empirical measurement should be performed to validate these preliminary impressions.

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