Game theoretic approaches in cloud and P2P networks: Issues and challenges

Georgia Koloniari and Angelo Sifaleras

Abstract Game theory constitutes a mathematical method for rational decision making in competitive and conflicting situations under specified rules, and thus is closely associated with decision theory. The applicability and usefulness of game theory has been already proved in the research area of peer-to-peer (P2P) networks and network optimization in general. P2P networks consist of autonomous nodes that not only collaborate for sharing and consuming resources, but also act independently and are governed by selfish motives. Thus, game theoretic solutions lend themselves well for problems arising in P2P networks. Also, game theoretic approaches have recently been employed in order to exploit the benefits of cloud infrastructures. The proposed work surveys the recent developments on game-theoretic approaches in P2P networks and cloud systems, and provides a classification of approaches dealing with a variety of problems encountered in the design and deployment of P2P and cloud systems.

1 Introduction

Game theory is a formal framework with a set of mathematical tools to study the complex interactions among interdependent rational players. Strategic games have found a number of important applications in economics, politics, sociology, etc. During the past decade, there has been a surge in research activities that employ game theory to model and analyze modern communication systems, due to i) the emergence of Internet as a global platform for computation and communication,

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ii) the development of large-scale, distributed, and heterogeneous communication systems, and iii) the need for robust designs against uncertainties.

P2P networks consist of autonomous nodes that not only collaborate for sharing and consuming resources but also act independently and are governed by selfish motives. Users are generally selfish in nature, for instance, distributed mobile users tend to maximize their own performance, regardless of the other users, subsequently giving rise to competitive scenarios. Consequently, game theoretic solutions are suitable for problems arising in P2P systems.

Cloud systems [60] is another environment in which game theoretic models find a natural application. In such systems, the cloud provider tries to maximize its profit and cloud users also expect to have the best resources available under their budget and time constraints. Therefore the allocation problem and the pricing strategies is one of the problems encountered in cloud systems that has been modeled using a game-theoretic approach.

Game theoretic approaches have been widely studied in the context of design of communication networks [1, 39, 47], design of wireless sensor networks [46, 48, 53], other applications in network optimization (e.g., traffic networks) [2, 27, 42]. However, although there is work on game theoretic models for P2P and cloud systems, there is a lack of a systematic classification.

In this paper, we survey recent developments in applying game theoretic models and techniques to deal with problems encountered in P2P systems and cloud infrastructures. Our goal is to categorize the different approaches with respect to the problems they solve, in order to show the wide spectrum of issues involved in both P2P and cloud systems that are appropriate for game theoretic solutions. By showcasing this wide variety, beyond a categorization of the related approaches, we also aim at indicating future application areas of game theoretic approaches both in P2P and cloud systems, and other emerging domains exhibiting similar characteristics such as the Internet of Things (IoT) [43].

The rest of the paper is structured as follows. In Section 2, we present recent developments in game theoretic approaches grouped according to the sub-domains of P2P networks and cloud systems. Finally, Section 3 concludes the paper.

2 Recent developments

This Section presents the recent developments in a number of problems in P2P and cloud systems, and namely, (i) network formation, (ii) content sharing and resource allocation, (iii) routing and replication, (iv) incentives, (v) video transmission over P2P, (vi) security, (vii) trust, and (viii) privacy.

2.1 Network formation

One of the first problems that was addressed based on game-theoretic modeling is the problem of P2P network formation. In P2P systems, each node (peer) in the network forms logical links to a selected subset of other nodes, its neighbors. Particularly in unstructured P2P systems, neighbor selection was initially random. However, as the routing and resource sharing algorithms use mainly variations of flooding and random walks to locate interesting resources, the neighbors of each node play a significant role in the performance of such algorithms.

Therefore, peer selection is modeled as a strategic game, in which each player (the peers), select which peers to connect to so as to maximize their own lookup performance [35]. Though most works consider only selfish motives, altruistic ones have also been studied [62]. Alternative games aim at forming an overlay network consisting of groups (clusters) of peers [25] which considers both selfish and altruistic peers or selecting super-peers in a hybrid P2P topology [26].

In all works, the cost function is the lookup performance and many factors are incorporated into its modeling such as the hop distance, network latency, the cost of links maintenance, the load distribution, availability, content locality and also trust and even personal preferences if they are available.

The combination of the strategies each peer selects yields the final P2P topology. To measure the performance of the game theoretic models, the price of anarchy is evaluated and also the existence of equilibria when those arise. Under selfish models there may or not be possible to attain one [25, 35]. Recent work has also explored the idea of bounded rationality players so as to better simulate the real-world context in which most decisions are based on limited information and the players have limited cognitive abilities [23].

The game of peer selection has also been applied in slightly different networks that follow the P2P paradigm, especially wireless and mobile networks. In [37], the problem of peer selection is applied in Device-to-Device communications, where the goal is similarly, to optimize the traffic offloading from the cellular level to the devices. Thus, the game is formulated as finding the optimal pairs of devices to link with each other.

2.2 Content Sharing & Resource Allocation

Content sharing is also a problem closely related to the network topology one we discussed above. After receiving or downloading a file, a peer needs to determine whether to share or cache the file. Each peer has to select between two strategies, either to share or not share the given file [51]. The factors that influence the strategy selection take into account the upload capacity of each node, the available bandwidth, fairness among peers and others. A complementary problem regards the incentives to limit selfish behaviors and is studied also when considering the strategies for sharing or not sharing resources [55]. Also reputation models have been com-

bined to the same end [14]. The problem becomes even more difficult considering the heterogeneity of the shared files. All files are not equally important or popular and each file may induce a different cost when cached.

Most approaches use evolutionary games to model the behavior of peers. Micro-macro dynamics reveal how the interactions about file caching among peers affect the caching condition in the whole system and agent-based dynamics are deployed [34]. Superior strategies now spread on a hop-by-hop basis, through neighbors interactions.

In cloud environments, a similar problem is that of resource allocation where game theoretic models are deployed for modeling dynamic resource allocation algorithms [61, 52] that maximize the cloud providers profits.

In [13], a hybrid system combining the benefits of p2p systems and content delivery networks, utilizes an auction-based resource scheduling mechanism that is envy-free and relies on the economic modeling of the hybrid system and its users. The objective function that is maximized is defined as the net profit of the content providers.

A non-cooperative game is used to model the problem of content delivery between peer swarms belonging to different ISPs. Content delivery deploys a proportional-fairness mechanism and the authors prove that their system reaches equilibrium states that are suboptimal but adequate as the price of anarchy remains bounded. [40]

2.3 Routing & Replication

Other issues related to content sharing and resource allocation, that also determine the performance of a peer-to-peer system is routing and replication. The routing problem of discovering resources of interest is also closely related to the problem of network formation, as the network topology is what determines the routing algorithms deployed. The game consists of peers cooperating to discover desired resources. The peers decide between cooperation or not based on the costs involved and their potential rewards and various approaches modeling variations have been proposed [32, 24].

A repeated game for modeling a distributed service discovery process is proposed in [33].The utility function of the players is based on network topological criteria and the distance to the search target. Also, an incentives-based mechanism is also used to avoid free-riding phenomenas. The authors show that under specific conditions the game between the collaborative players that discover and consume services reaches a Nash equilibrium.

Replica placement when done with global knowledge can optimally make decisions to improve the overall system performance. Game modeling has been applied to cope with local decisions based on limited knowledge, the selfish behavior of peers [44, 63] and even malicious behaviors [15]. Similar games have been deployed

for other large-scale distributed networks that exhibit common characteristics with P2P systems [45, 29].

2.4 Incentives

It is widely known that, selfish behavior of peers leads to free-riders. Thus, in order to cope with free-riding usually incentives are offered to peers for increasing their contribution to the system. Such approaches include the following:

- *Punishment-based schemes: tit-for-tat* approach for file-sharing
- *Reward based schemes*: money rebate from the service fee, virtual credits, reputation record

Other rewards schemes are as follows:

- *Payment based schemes*: a pricing scheme is optimal if it induces a Pareto non-cooperative equilibrium, e.g., linear pricing.
- *Differential service*: in which peers obtain different qualities of service depending on their contribution levels.
- *Repeated game*: peers can reciprocate service to each other based on private or public history
- *Intervention*: the system treats peers differentially based on their contribution to the system

Recently, Sun et al. [50] proposed a novel incentive mechanism using Accumulated-Payoff Based Snowdrift Game (APBSG) model for the improvement of the cooperation frequency for P2P networks. Their study showed that, their proposed APBSG model was able to reduce the sensitivity of cooperation to the selfishness of nodes; thus promoting the cooperative behavior in P2P network.

Also, Cui et al. [9] verified the effectiveness of a reciprocation-based incentive mechanism, based on spatial evolutionary game theory. The authors proposed a transaction overlay network for modeling the transaction relationships of peers and tested various scenarios with heterogeneous and homogeneous benefits of services.

Furthermore, Kang and Wu [22] formulated a Stackelberg game for maximizing the utilities of the downloaders and the revenue of the uploader, by considering peers' heterogeneity and selfish nature. The proposed resource allocation scheme was shown to be effective in stimulating the peers to make contribution to the P2P streaming system.

Other recent game theoretic approaches regarding incentives include the works by Jin et al. [20], Park and van der Schaar [41], Wang et al. [54], and Wu et al. [58].

2.5 Video transmission over P2P

There are peer-to-peer systems that are specifically designed for multimedia sharing. These systems take into account multimedia characteristics, and thus stringent delay constraints appear. Furthermore, video quality is not simply a function of the download rate. Regarding the upload credit rate, different pieces of the bit stream may have significantly different impact on the video quality. Also, credits allow peers to offer different prices for various parts of their multimedia content based on their perceived importance. A foresighted resource reciprocation game includes:

- A state of peer i represents the set of discretized received resources (in credits per state) from the peers in its group i.e., its neighbors
- An action of peer i is its resource allocation (in credits per state) to the peers in its group
- The transition from a current state to a future state through an action is governed by the state transition probability that is learned online through the behavior of peers
- Reward R_i: The utility of peer i downloading its desired multimedia content from other peers in its group is defined as the total credit downloading rate.
- Reciprocation policy: Each individual peer's ultimate goal is to maximize the sum of its expected rewards to determine the best strategy

Such a game deals with the following issues:

- Free riders: free-riders are cut out using a credit line mechanism
- Delays: minimum-delay streaming is achieved by uploading data to the most deprived peers

Hu et al. [18] formulated problems, raised in mobile social video sharing, as decentralized social utility maximization games. The authors, presented a general framework for modeling the information diffusion and utility function of users on a public cloud-assisted architecture.

A game-based Adaptive Bitrate Streaming (ABR) method was recently proposed by Lin and Shen in [28]. The authors formulated the bitrate adaptation problem in ABR as a noncooperative Stackelberg game; where video-on-demand (VoD) service provider and the users are players. According to the presented experimental results it was shown that, the proposed game-based method can save cloud bandwidth consumption and provide high user satisfaction, compared to other existing methods.

Mahini et al. [31] suggested a new game theoretic mechanism for P2P live video streaming. The objectives of the proposed framework are the minimization of loss rate in video data transmission and the prevention of free-riding. By analyzed the proposed game, the authors obtained a Nash equilibrium for the determination of a peer's best strategic response for participation in the video chunk distribution.

Other recent game theoretic approaches regarding video transmission over P2P include the works by Asioli et al. [3, 4], Maani et al. [30], and Mostafavi and Dehghan [36].

2.6 Security

P2P systems leverage network topology information to optimize performance. Nodes rely on information reported by a subset of participating nodes and on latency measurements. Malicious nodes can lie in the reports about their own latencies, or they can influence the measurements conducted by other nodes. A game theoretical model allows us to assess the strategic interactions between the attacks and defenses, and to model an advanced adversary who knows how and what defense strategies are used; and can adjust his attack strategies accordingly.

Chen et al. [7] suggested a two-player game theoretic framework for modeling the fragments exchanging behavior between neighboring mobile peers. The goal of their work is to prevent Message Dropping Attacks (MDAs) in mobile P2P live streaming systems. Based on the experimental results, the authors showed that, their strategy can prohibit mobile peers from cheating on their private information and dropping messages.

A randomized, game-theoretic approach for computing the optimal positioning of Intrusion Detection Systems (IDSs) in a P2P network, was recently proposed by Narang and Hota [38]. Their method aims at minimizing the probability of a successful attack by randomly distributing the responsibility of running the IDSs between the peers.

Jin et al. [19] implemented a repeated two-layer single-leader multi-follower game for obtaining a quantitative understanding of the fundamental tradeoff between the organizations' privacy and the intrusion detection accuracy. According to the findings of their game-theoretic analysis, the authors derived the expected behaviors of both the IDSs and the attacker and obtained the utility-privacy tradeoff curve.

Other recent game theoretic approaches regarding security include the works by Becker et al. [5] and Siwe and Tembine [49].

2.7 Trust

Domingo-Ferrer et al. [10] introduced the notion of co-utility and studied how existing protocols can become self-enforcing by including reputation mechanisms. Also, the authors demonstrated a case study about a co-utile P2P privacy-preserving query submission to a database or web search engine.

Wang et al. [56] proposed a trust measurement model based on game theory for addressing the problem of accurately calculating the trust degree in social networks. The effectiveness of the proposed trust measurement model was verified by simulation results. Furthermore, the authors also suggested a punishment mechanism for solving the free-riding problem in social networks.

Hawlitschek et al. [16] presented an experimental framework with several applications regarding the trust game mechanics, (e.g., repeated interactions, experience, learning effects, or endowments and payment protocol) in the sharing economy.

Recently, Gao et al. [12] applied a game theory approach in order to investigate the acceptance of a cloud data access control system based on reputation. Their findings indicate that, the effectiveness of the proposed compensation and punishment mechanisms increased cloud storage rate and restrained dishonest system entities.

Other recent game theoretic approaches regarding trust issues include the works by Chen et al. [8], Gao and Guo [11], and Xiang et al. [59].

2.8 Privacy

As content sharing among the peers is one of the core functionalities of P2P systems, the problem of privacy perseverance is also a very important one. Cloud systems that offer storage and searching functionalities also deal with the same problem and privacy concerns also arise in cloud environments particularly in federated clouds.

Some limited work shows that game-theoretic models show promise when modeling the privacy problem as well. For preserving the privacy of location based services a game that models a privacy-performance tradeoff has been designed [21]. The main idea is using game theory to deal with free riding phenomenas appearing during collaborative caching, where redundant query results need to be shared among users so as to achieve k-anonymity.

Another application is for multi-party secure computation to deal with collusion attacks [57]. The paper presents a collusion deterrence game while modeling different players preferences so as to account for heterogeneous participants.

Also, combined with other methods such as cryptography, game theoretic concepts have been exploited to deal with the problems of privacy in P2P systems focusing on the collaboration of the players and aiming for private content sharing [6, 17]. In particular, in [6], data mining applications that may trigger privacy concerns are considered. The applications are modeled as multi-party games where each node selects different strategies for communication, computation, collusion or privacy attacks depending on their expected gain.

In [17], the authors consider devices on a microgrid and utilize a p2p energy exchange system to better utilize the available energy without burdening the main grid. The problem is modeled as a series of optimization problems, in which the peers aim to preserve their privacy using a secure communication protocol.

3 Conclusions and future work

A short survey of recent game-theoretic approaches applied in P2P networks was presented. The approaches were grouped according to the different application subdomain of P2P networks and cloud systems. A variety of issues was presented, starting from issues in network design, resource allocation and routing to issues

related to security, trust and privacy showing how versatile game-theoretic solutions can be.

Furthermore, the study of game theoretic applications with an emphasis in the research area of Internet-of-Things (IoT), could be a very interesting future extension of this work.

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