Game theory approach to peer-to-peer video streaming: a comprehensive survey

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Abstract: Recent reports and forecasts indicate video is the most important part of the internet traffic. This traffic is the result of increasing video applications, also the high expectations of today users. In fact, streaming HD videos with minimum initial buffering time and interruption forms the QoE backbone. Therefore, resource provisioning for this demands is very challenging and the scalability of these systems depends on spending a high cost on preparation new resources or taking the advantage of users' abilities in the form of a peer-to-peer (P2P) system. Although P2P architecture can significantly improve scalability, it has severe management complexity challenges. The dynamic nature and the autonomy of peers are the prominent reasons for this issue. Because of the strategic context in P2P video streaming and due to the existence of conflicting actions for participant entities in such systems, using game theory has been very interesting as a mathematical tool for modelling and analysing in recent related investigations. Due to the multitude of these methods, the lack of a comprehensive review is intensively palpable. This paper seeks to fill this research gap especially with focus on applying non-cooperative games to P2P video streaming resource allocation.

Keywords: peer-to-peer; P2P; video streaming; game theory.

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1 Introduction

Recent reports and forecasts show that video applications are one of the most important and challenging trends in the internet. ComScore which is a US global media measurement and analytics company reports that 182.5 million Americans watched 39.3 billion online content videos in March 2013. Also, Google sites (YouTube.com), with 153.9 million unique viewers ranked as the top online video content provider in the same month. Facebook with 63.8 million, VEVO with 52 million, Yahoo! Sites with 50.3 million and Viacom Digital with 43.8 million won the next positions respectively. This report reveals that more than 39 billion video content views occurred during the month (ComScore, 2013). Cisco in a forecasting about visual networking claims that the consumer internet video traffic will be 80% of all consumer internet traffic in 2019. Also, the report states that, high definition (HD) videos will be 70% of IP video-on-demand (VoD) traffic in 2019, up from 59% in 2014 (Cisco, 2015). In another forecast, Cisco states that 55% of total mobile data traffic is dedicated to videos in 2015 and this percent will reach to 75% by 2020 (Cisco, 2016). Worse still, the growth of video in both fixed and mobile contexts leads to increase acceleration of busy-hour traffic. In fact, in contrast with general web usage which is occurred throughout the day, videos more has watched during evening hours and has a primetime. Therefore, more video application means more traffic during the peak time. Globally, busy-hour traffic in the mobile networks will be 88% higher than average-hour traffic by 2020, while this is 66% in 2015 (Cisco, 2016). So, increasing video application users, and also their level of expectations lead to fundamental challenges in resource provisioning for this applications. Generally, the video streaming has four fundamental demands, as follows:

- Real-time constraints, which refers to receive timely video content.
- Bandwidth constraints, dictates that the downloading rate always must be higher than the video rate.
- Quality-of-experience (QoE or QoX), which specifies the satisfaction level of the user of an application or service (Raake and Egger, 2014). Streaming the HD videos with the minimisation of setup time, packet loss and interrupt occurrence are prominent goals in order to ensure QoE for video applications.
- Scalability, in terms of geographic distribution and number of users.

Two types of application architectures can be considered in the internet: client/server (C/S) and peer-to-peer (P2P). P2P is more scalable and more complex to manage in contrast with C/S (Kurose and Ross, 2012). Due to significant economic savings, using P2P architecture has been very interesting to video streaming in the internet recently. However, P2P approach imposes additional constraints on video streaming applications that endanger its success. Dynamic nature and autonomy of peers are the prominent examples of these constraints. Because of peer churn in the P2P system there is no guarantee for the availability of an existing resource for a second later. Note, an important part of the P2P scheme power depends on participant peers resource sharing, while selfishness of peers is considered as a serious threat in this regard. Free-riding phenomenon is a result of this issue.

Game theory and mechanism design can model the interactions among strategic agents. While game theory is fond of games analysis, mechanism design concerned with designing games to achieve desirable outcome. Traditionally, game theory has been widely used in economics, business, political science, philosophy, sociology, biology, industrial engineering, inventory and supply chain management. In recent years, game theoretical approaches have been very interesting in computer science and electrical engineering. Currently, these are the notable and the active approaches of research for inter-disciplinary problem solving (Narahari, 2014). The strategic nature of P2P video streaming systems has caused the game theory to play an important role in this field of research. In other words, interactions between decision-making entities in such a system can be modelled by a game. Then by the help of the analytical tools of game theory, analysis, forecast or design an appropriate mechanism for this system will be done. Due to the increasing number of researches in this field, a comprehensive review of the related researches to determine the roadmap for researchers seems to be essential, while, this research domain suffers from the lack of such survey. To this end, this paper seeks to fill this research gap especially with focus on applying non-cooperative games to P2P video streaming resource allocation.

1.1 Contributions

In 2002, Apostolopoulos et al. provided a brief overview of the concepts, algorithms and systems of video streaming. Shortly before this research, a survey of application layer techniques for adaptive streaming was undertaken by Vandalore et al. (2001). They focused on compression algorithm features, layered encoding, rate shaping, adaptive error control, and bandwidth smoothing in the application level techniques. In 2007, Marfia et al. surveyed P2P streaming system in the time. They studied the available architectures of P2P video streaming and a set of experiments on a popular P2P system. Liu et al. conducted a survey of opportunities and challenges in P2P internet video broadcasting in Liu et al. (2008a). This paper reviewed the major issues associated with the design of broadcast overlays. Li and Yin (2007) studied the issues, approaches and challenges of live P2P video streaming. In 2008, Liu et al. (2008b) surveyed the P2P video streaming systems of the time. They reviewed the live and VoD P2P video streaming systems with different overlay structures such as mesh, single tree and multi tree. In 2011, Abboud et al. conducted an analytical survey of resilient P2P video streaming. They classified the different challenges in P2P streaming and then present and analyse the possible solutions for them. Zhang and Hassanein (2012) provided a survey of P2P live video streaming with an algorithmic perspective. Finally, Thampi (2013) reviewed P2P video streaming schemes. As stated earlier, despite many game theoretical studies have been conducted in P2P video streaming both before and after 2012, the lack of a comprehensive survey of these approaches is obvious clearly. This work not only complements these earlier surveys and reports but also tries to review game theoretical approaches in this domain. Of course, the main focus of this paper is on non-cooperative approaches which are employed for P2P video streaming resource allocation. The key features of this work are summarised next:

- detailed review of notions and feasible implementation methods for video streaming over the internet

- a broad overview of several past and recent P2P video streaming approaches, along with providing a detailed classification of them
- the introduction of a large number of P2P video streaming systems implemented so far
- brief overview on game theory and mechanism design concepts
- comprehensive review of game theoretical approaches to P2P video streaming, along with express their cons and pros
- discussion on new trends and future works in game theoretical approaches to P2P video streaming.

The remaining of this paper is structured as follows: P2P video streaming concepts, terminology and literature review are presented in Section 2. Section 3 represents game theory approach to P2P video streaming and related works. Finally, conclusion is described in Section 4.

2 Video streaming on the internet

In recent years, video streaming has been one of the most important and pervasive applications in the internet. Also, forecasts and recent reports suggest that the largest share of the internet traffic will belong to video applications in the coming years. Due to this ever-growing need and the importance of this issue, many researches are conducted in this area. So, to bring better understanding of concepts, challenges and limitations, the related works should be reviewed and summarised for future works. In this section the literature review on video streaming especially P2P scheme for this popular application is presented.

2.1 Video streaming system architecture

Despite the less than two decades age of the media streaming on the internet, nowadays, millions of users with the dramatic growth are watching online sport competitions, news, video clips, etc. (Kozamernik, 2002). In general, there are two modes for media transfer in the internet: downloading mode, so that the watching video content is possible only after the complete downloading. Time elasticity depending on the video size and available throughput are the prominent features of this mode. But streaming is another mode. Watching after complete downloading is not necessary in this mode and playing the media is occurred simultaneously with the download and decode of video content. Video streaming architecture can be evaluated in six areas as follows:

- *Media compression and encoding:* to effective streaming, media data rate should be less than the user’s connection speed (Kozamernik, 2002; Asioli et al., 2012; Huang et al., 2009). Therefore, video/audio compressing and encoding are one the most important research areas in the media streaming field. More compression leads to decreasing the media rate but it is important to note that the high compression does not have a negative impact on the quality of the media.

- *Quality-of-service (QoS) in the application layer:* this issue focuses on congestion and error control in the application layer. Congestion control can improve the data loss rate and error control can increase the quality of video when the data loss is occurred.
- *Media distribution services:* the network layer should reduce packet loss and latency same as the application layer. Multicast and content replication are two examples of these proceedings.
- *Streaming servers* is one of the most important entities in media streaming undoubtedly. These servers must be able to stream the media under the time constraints.
- *Synchronisation at the receiver side:* the receiver must be able to play media exactly the same as what is streamed from the server. For example, the actor's lips must be sync with his voice.
- *Media streaming protocols:* it is necessary to define standard protocols between server and receivers to fulfil some issues such as network addressing, transport and session control.

2.2 Video streaming challenges

Due to the nature of video streaming application and increasing its users, some important following challenges are raised:

- *Real-time constraints:* certainly, the proper functioning of a video streaming system not only depends on how to play video, but also depends on the playtime. In other words, the production and reception of video chunks should not be delayed from playback.
- *Bandwidth constraints:* to watch video correctly, the download bandwidth rate must be greater than the video rate. So, higher video rates leads to more download bandwidth need.
- *QoE:* viewers' satisfaction is the most important parameter in the performance evaluating of a video streaming system. Although, it is possible to be a correlation between QoE and QoS, but these concepts are different. Indeed, QoS focuses on the system's performance aspects of telecommunication systems while QoE focuses on the user or person's ICT service, application or system (Raake and Egger, 2014). Note that, difficulty of measuring QoE leads that, providing it become more challenging in comparison with QoS provisioning. Low setup time (initial buffering), reduce video chunks loss ratio, maintain the continuity of play and increase the quality of videos can affect on QoE in video streaming applications. Users' demands in this area are insatiable and so their satisfaction is very challenging.
- *Scalability:* as previously discussed, using video streaming applications have grown in recent years. Also, this growth will continue in the coming years. So, scalability in the terms of the number of users and geographical distribution is very challenging in this domain of application.

2.3 Video streaming approaches

In the last two decades, different approaches have been presented for video streaming. *Real-time* and *high quality* video playback with the scalability for a large number of users around the world are three important requirements in these approaches. For example, streaming a TV program with MPEG-4 quality for one hundred million viewers requires 1.5 Tbps aggregated bandwidth (*The State of the Art of P2P Video Streaming*, n.d.). There are three approaches to video streaming on the internet as follows:

- *IP multicast*, this is a network layer scheme. Internet routers must support multicast routing to implement this method. Indeed, routers distribute video content packets to the destinations via multicast sessions, instead of sending multiple copies of one video content packet by the video source. Although with IP multicast, the core network traffic is decreased significantly, but it has several important weaknesses as follows:

  a it is required to maintain the multicast groups in core routers

  b slow deployment, means that it needs to change the equipment in the network infrastructure

  c the inability to take advantage of the higher layers such as error control, congestion control and flow control.

  Actually this mechanism violates the end-to-end design principles and it is not scalable and cost effective.

- *Content distribution/delivery networks (CDNs)* are a set of network elements arranged side by side, which aims to efficiently deliver content to end-users (Kaashoek and Douglis, 2001). This concept emerged through the Web to answer the need for long-distance transmission of large amounts of content in 1998 (Vakali and Pallis, 2003). In other words, a CDN provides services with repeated or replicated content to improve network performance through maximising bandwidth, availability and integrity (Pallis and Vakali, 2006; Pathan and Buyya, 2007). Akamai (2016) and Limelight (2016) are two examples of CDN for video streaming. Akamai network has approximately 20,000 servers which are distributed via 1,000 networks in 71 countries and Limelight servers are distributed in 72 countries which are used more to VoD applications (Pathan and Buyya, 2007). The most important problem in the use of CDN is the high cost of its establishment so that small and medium and even some large companies cannot provide it (Kangasharju et al., 2002).

- *Application layer multicast:* in this way, multicast capability exists for the end systems at the application layer. In fact, end systems multicast data via creating an overlay network. Note that, overlay network contains logical links between network nodes in the application layer. Ease of deployment and end-programmable host are two important advantages of this method. P2P system is an application layer multicast instance.

2.4 P2P video streaming

As mentioned before P2P systems are the clear examples of the application layer multicast scheme. At first, P2P systems were used to file sharing. But nowadays, vast capabilities and applications can be considered for P2P scheme. Video streaming is one of these applications. BitTorrent (2014) is one of the most famous and perhaps the most successful P2P file sharing. Also, PPLive, CoolStreaming and AnySee are the practical examples of P2P video streaming systems. P2P video streaming combines conflicting traits such as low bandwidth, high quality and scalability (Kang and Wu, 2013). P2P video streaming is categorised from different perspectives that will be described later.

2.4.1 Overlay structures

One of the factors in P2P video streaming systems classification is their overlay structures. Accordingly, tree-based and mesh-based can be considered (Wen et al., 2006; Marfia et al., 2007). Also, the hybrid of these structures exists (Shen et al., 2013).

- *Tree-based overlays:* in tree-based overlays video source and each peers are connected together logically in a hierarchical structure. This structure is divided into two categories: single and multi tree. The first single tree-based P2P video streaming were ESM and Overcast (Chu et al., 2002). Figure 1 shows a sample of single tree-based structure. Lower depth in tree-based structure is an advantage because of closing to the source and lower latency. So creating a tree with the minimum height is an ideal goal which depends on the upload bandwidth of nodes. However, the reliability and fault tolerance principles would recommend contradictory idea (Liu et al., 2008b). An orphan peer, which occurs due to the parent leave, is another important challenge in tree-based overlays. Figure 2 depicts the orphan peer problem. Peer churn can significantly affect the tree-based overlays performance (Thampi, 2013). Construction and maintenance of tree can be implemented centralised and distributed (Tran et al., 2003). The inability to take advantage of leaf nodes upload bandwidth is another major problem in single tree-based overlays. Multi-tree structure was proposed to solve the latter problem (Castro et al., 2003; Kostić et al., 2003). In this case, server splits the stream into multiple sub-streams and there is a tree for each sub-stream. Each peer participates in all trees to receive all sub-streams, which is a leaf node in some trees and internal node in another one. Figure 3 shows the example of multi tree structure.
- *Mesh-based overlays:* according to tree-based overlays weaknesses, mesh-based structures have been used in many recent P2P video streaming systems (Pai et al., 2005). There is no single point of failure in mesh-based overlays in contrast with tree-based. Also, in a mesh-based structure the logical links are not static and each peer can establish or terminate a link dynamically. Simulations conducted by researchers in Magharei et al. (2007) shows that mesh-based systems are more efficient than tree-based. Connection between two peers is established based on mutual agreement that follows some rules such as:

a workload and available resources on both sides like the number of connections, download/upload bandwidth, CPU and memory usage

b the potential quality of connection includes latency and packet loss on logical link between two peers

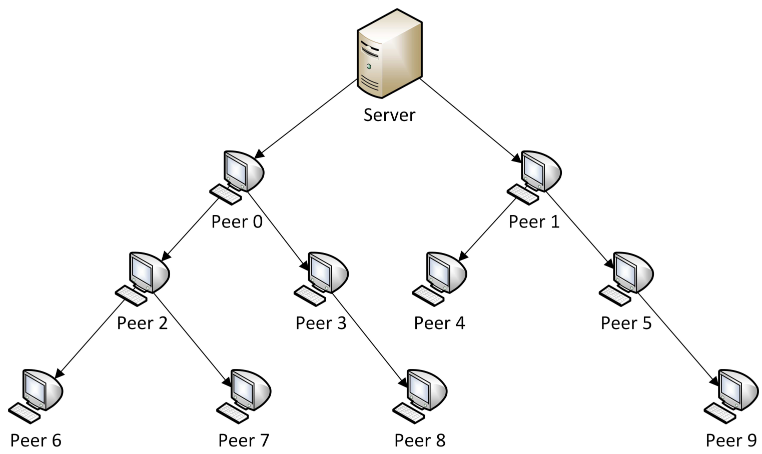
c access to required video content which specifies the possibility of needed data access for both sides.

First copy distribution is another issue in mesh-based overlays. In contrast with tree-based, the first receivers of video content are unclear. Some algorithms like give-to-get are proposed to address this problem (Mol et al., 2008).

- *Hybrid overlays*: in order to take advantage of the benefits of both mesh-based and tree-based overlays, in recent years, many researches have been done to provide a hybrid structure. For example PRIME is a two-phase P2P video streaming system (Magharei and Rejaie, 2009). In the first phase, a tree takes shape based on the hop distances between each node and the video server. In the second phase, a mesh-based overlay is established in each level of the tree. Chunkyspread (Venkataraman et al., 2006) is another example of hybrid overlay structure. In this system a multi tree structure is built on the mesh overlay. Wang et al. (2007, 2008) proposed a two-tier system. In the first tier, a tree-based backbone is created from stable nodes and in the second tier both of stable and unstable nodes create a mesh-based overlay.

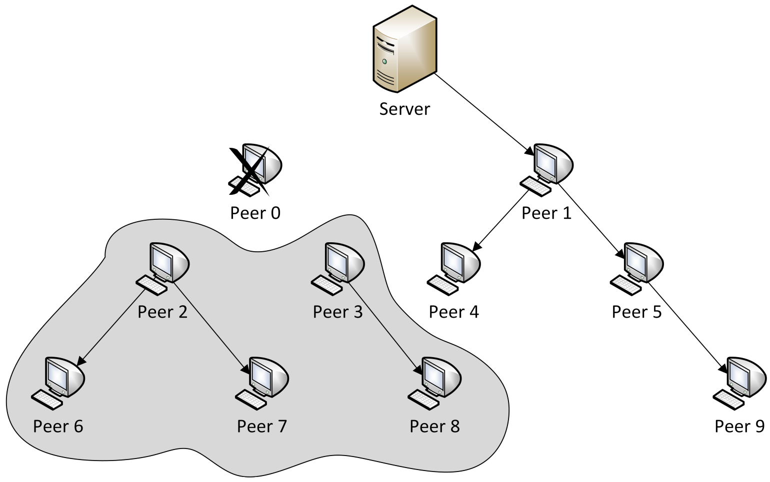
  This structure increases system robustness against peer churn. The stable and unstable nodes detection is a challenging process which is addressed in some researches such as Banerjee et al. (2003).

Figure 1 Example of single tree-based overlay structure (see online version for colours)



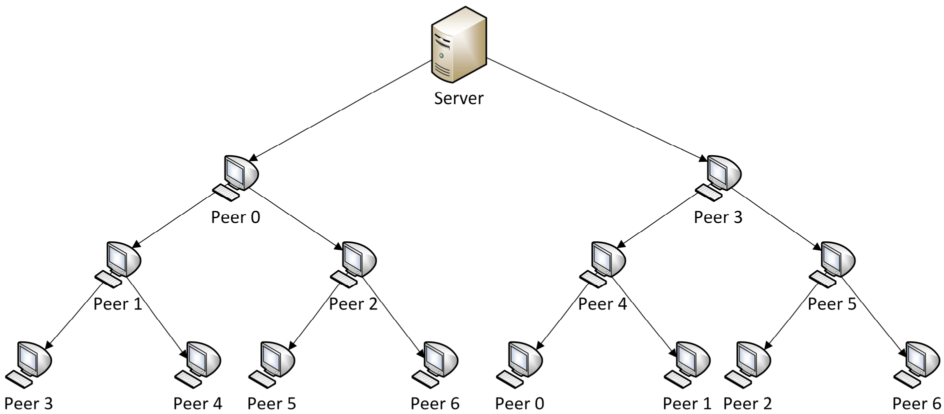
Source: Liu et al. (2008b)

Figure 2 Orphan peers problem in a single tree-based overlays; after leaving the peer 0, all his children (peers 2, 3, 6 and 8) become orphans (see online version for colours)



Source: Liu et al. (2008b)

Figure 3 Example of multi tree-based structure (see online version for colours)



Source: Liu et al. (2008b)

Notes: In multi-tree structures, video is divided into multi substreams. Each peer contributes as a internal node at least in one substream (subtree) and can be found as a leaf node in other subtrees. So, this technique prevents from the upload bandwidth wasting of leaf nodes in the tree structure.

2.4.2 Demand management techniques

How to meet the needs of peers is another important design issue in the P2P video streaming system which is categorised into push, pull or the combination of both types. In push, the upstream peer sends the video content to downstream and in pull mechanism, the downstream peer can select the upstream to send his request (Chang, n.d.). The nature of tree-based overlay is more compatible with push and mesh-based is more inclined towards pull. Of course, this is not a certain law. Hybrid model which is a combination of these two ideas can operate better than each in term of latency, overhead and robustness (Alghazawy and Fujita, 2011). This combination may lead to the hybrid of tree-mesh overlays or not. Take CoolStreaming as a push-pull P2P video streaming with hybrid overlay structure. Also, Ghanbari et al. (2012) presents a push-pull demand management mechanism on a mesh-based overlay structure. As other examples for push-pull-based P2P video streaming systems with hybrid structure work done in Gau et al. (2008), Wang et al. (2010b) and Zhao et al. (2005) can be cited. Also in Li et al. (2008) and Lo Cigno et al. (2008) another push-pull P2P video streaming with mesh-based overlay can be found. Finally, with comparison of these approaches the following results are obtained:

- Pull-based systems are more resistance in peer churns and generally more fault tolerable (Zhang et al., 2005b).
- The probability of duplicate data reception in pull mechanism is more than push-based.
- There is more need for large buffer to store received video chunks in pull-based system (Zhang et al., 2005a).
- Increasing the hop distance between upstream and downstream peers can affect on latency and consequently on the performance of both approaches. The difference is that this distance and accordingly latency is variable in pull, but it is almost constant in push.
- Chunk holders tracking is another challenge in pull schemes. Frequently transfer buffer mapping is the classical method for solving this problem which may leads to problems such as traffic overhead and peer cheating.

Figure 4 P2P video streaming taxonomy cube

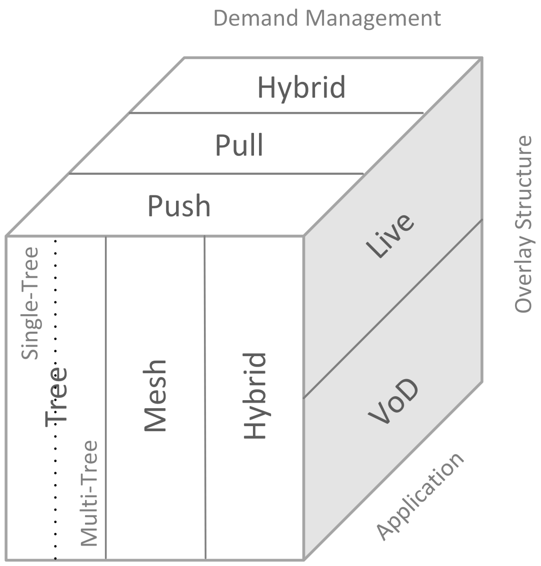


Table 1 Famous and important P2P video streaming systems

Name	*Ref.*	*Overlay structure*	*Demand management*	*Application*	*Comments*
NICE	Project NICE at University of Maryland (2014)	Single Tree	Push	Live	Project NICE at University of Maryland
SpreadIt	Deshpande et al. (2008)	Single Tree	Push	Live	Stanford University
ESM	Conviva (2016)	Single Tree	Push	Live	Carnegie Mellon University
ZigZag	Tran et al. (2003)	Single Tree	Push	Live	Central Florida University (improve NICE performance)
SplitStream	SplitStream (2016)	Multi Tree	Push	Live	Microsoft Research Center
CoopNet	Thampi (2013)	Multi Tree	Push	Live/VoD	Suitable for low quality video
AnySee	Liao et al. (2006)	Mesh	Push	Live	Intera overlay optimisation
Chainsaw	Pai et al. (2005)	Mesh	Pull	Live	Inability to deal with free-riders
PPLive	Spoto et al. (2009)	Mesh	Pull	Live	Fault tolerable with two buffering system
DoNet	Zhang et al. (2005b)	Mesh	Hybrid	Live	CoolStreaming
SopCast	Lu et al. (2009)	Mesh	Pull	Live	Non-video data exchange overhead
GridMedia	Thampi (2013)	Hybrid	Hybrid	Live	For the CCTV Spring Festival Gala 2005
PRIME	Magharei and Rejaie (2009)	Mesh	Hybrid	Live	Inefficient in peer churn conditions
HyPO	Byun and Lee (2009)	Hybrid	Hybrid	Live	Bootstrap server is single point of failure
mTreebone	Wang et al. (2010a)	Hybrid	Hybrid	Live	Simon Fraser University and Microsoft Research Asia
P2Cast	Guo et al. (2003a)	Tree	Hybrid	VoD	Inefficient in peer churn conditions
P2VoD	Do et al. (2004)	Tree	Push	VoD	Unsuitable for asymmetric peers
oStream	Cui et al. (2004)	Tree	Push	VoD	Using of Minimum Spanning Tree
DirectStream	Guo et al. (2003b)	Tree	Push	VoD	Directory-based peer-to-peer video Streaming
BASS	Dana et al. (2005)	Mesh	Pull	VoD	BitTorrent Assisted Streaming System
Kangaroo	Thampi (2013)	Mesh	Pull	VoD/Live	Prolongation of response to VCR operations
BiToS	Vlavianos et al. (2006)	Mesh	Pull	VoD	Based on BitTorrent

2.4.3 P2P video streaming applications

Generally, there are two applications for P2P video streaming: live videos and VoD. Each application has special properties, requirements and limitations. In live streaming all viewers watch the same and synchronised video, so the real-time constraints satisfaction is very important. In contrast, viewers can watch arbitrary different videos and from different times. In fact, VoD is the interpretation of "Watch anything and anytime you want". Therefore, resource provisioning for VoD is more challenging. Some systems simplify the definition of VoD by considering that viewers watch the same video but from different times (Guo et al., 2003a). In this system a tree-based structure is used. Also, Dan and Sitaram (1996) have used cache-and-relay technique. DirectStream (Guo et al., 2008) is another practical example of employing this approach for simplified VoD application. Probably BiToS (Vlavianos et al., 2006) is the first P2P mesh-based VoD system. Annapureddy et al. (2007) and Guo et al. (2006) improve the performance via efficient scheduling for chunks downloading. In these schemes the priority of chunks which are closer to the play back is more than other chunks.

NICE (Project NICE at University of Maryland, 2014) is one of the most popular single tree-based P2P live video streaming. SpreadIt (Deshpande et al., 2008; The Stanford Peers Home Page, 2016), ESM (Conviva, 2016) and ZigZag (Tran et al., 2003) are other examples for P2P live streaming with single tree overlay. SplitStream (SplitStream, 2016) and CoopNet (Thampi, 2013) are famous multi tree-based P2P live streaming. SopCast (Guo et al., 2003b), DONet (CoolStreaming) (Zhang et al., 2005b), HyPO (Byun and Lee, 2009) and mTreebone (Wang et al., 2010a) are other examples for P2P live video streaming with mesh or hybrid overlay structure. In summarise, the P2P video streaming taxonomy cube is presented in Figure 4. Also, Table 1 shows the category of some famous and important existing P2P video streaming systems according to the discussed taxonomy.

3 Game theory approach

Game theory is a mathematical tool for modelling and analysis of conflict and cooperation between rational decision makers (Myerson, 2013). Game in the game theory refers to an interaction involving players or decision makers who are intelligent and rational. Rationality means the player acts based on maximising his payoff. Also the capability to compute his best strategies is interpreted to intelligence (Narahari, 2014). Interactions between existing entities in a P2P video streaming can be modelled as a game. Also, the strategic nature and the existence of conflicting actions in the context of P2P systems motivate researchers to use game theory and mechanism design in this area. Note that mechanism design focuses on game designing to achieve desirable outcome. In fact mechanism design is reverse engineering a game. Before examining game theoretical approaches to P2P video streaming, some important concepts and terminologies are discussed.

3.1 Games taxonomy

Games are categorised from different perspectives. Understanding this taxonomy is very essential for creating a standard terminology before using the game theory.

- *Static vs. dynamic game:* when in a game all timing assumptions are overlooked and in such a way apparently all players make his decisions independently and simultaneously, this game is called static (Myerson, 2013). Conversely, in a dynamic game, players select their act after playing their opponent. Rock-paper-scissors is a static and chess is a dynamic game.

- *Normal vs. extensive form:* there are two standard forms to display a game. In normal or strategic form a game is represented by $\Gamma =< N, (S_i), (u_i) >$ that N determines a set of players, (S_i) refers to the set of possible actions and (u_i) is a set of payoff or utility function for them (Tadelis, 2013). In many cases, especially in two-player game, utility function presents in form of a payoff matrix. In extensive form, a game is represented by a hierarchical structure like a tree. Each node of the tree determines a decision position with few exceptions, and each decision creates a branch in this structure. Static games are more compatible with normal/strategic form while dynamic ones are more consistent with extensive form, although this is not a permanent law.

- *Complete vs. incomplete information:* in a complete information game, four following elements must be as common knowledge (Tadelis, 2013):

  a all possible actions for all players

  b all possible outcomes in the game

  c how each possible combination of actions affects on the game outcome

  d preferences of each player according to the game outcome.

  Note that a fact such as F is common knowledge, if everyone knows it and knows that everyone knows it. But if at least one player has private information at the beginning of the game, this game is called incomplete information (Narahari, 2014). In other words, in an incomplete information game at least one player has different types.

- *Perfect vs. imperfect information:* in a perfect information (dynamic) game, all history of game is appeared perfectly for all of the players. In contrast, a (dynamic) game with some unclear history for some players is called an imperfect information game.

- *Cooperative vs. non-cooperative game:* a non-cooperative game has three following features (Bauso, 2016):

  a each player tries to maximise its outcome by choosing the best response which is based on its knowledge of others actions

  b players are not forced to accept any agreement on joint actions to achieve optimal group outcome

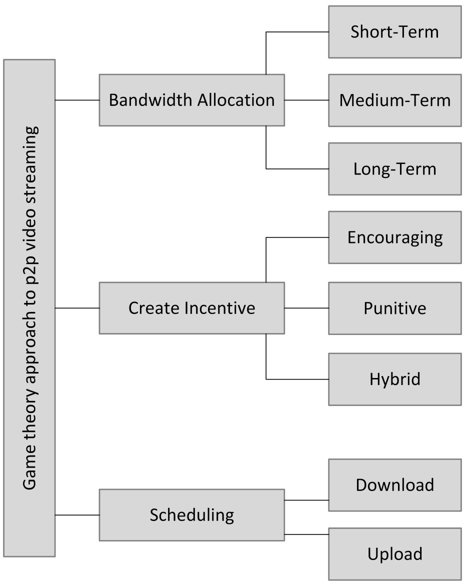
  c there is no pre-play communication stage.

  Non-cooperative games have been considered more, while, researchers were able to cover a wider range of applications with the help of cooperative games.

3.2 Application of game theory in P2P video streaming

Generally, game theory has been used to solve three important P2P video streaming challenges. These challenges are: bandwidth allocation, create incentive and optimal scheduling. Bandwidth allocation can be short, medium and long term. When a peer allocates its bandwidth during to a chunk transmission, the short-term allocation is occurred. In medium-term, a peer allocates its bandwidth longer than few chunks transmission time. For example in some auction-based methods, time is divided into downloading and bidding periods and upstream peers allocate their bandwidth during downloading period to downstream peers. Finally, when the time of allocation is longer than more chunks exchanging time, the long term is considered. For example in some push-based P2P streaming, the logical topology or overlay structure determines the bandwidth allocation which is long-term if the constructed overlay is relatively stable. Because of peers are self-interested, creative incentive is a very important challenge in P2P systems. Since the participation in P2P systems is not free for participants, rationality of peers dictates them not to be cooperative. So designing mechanisms to create incentive is highly regarded. Free riding is an inherently potential phenomenon in P2P systems. In a general definition, a free rider is a peer who downloads its required chunks without any uploading (Asioli et al., 2012). Ramaswamy and Liu (2003) prove that evaluating the performance of P2P file sharing system without paying attention to free riders is not acceptable. Investigations on Gnutella show that increasing free riders can be very harmful for its performance (Hughes et al., 2005). Despite efforts from researchers, this challenge remains in P2P systems. For example, Teng and Cheng (2013) propose an efficient free-riding mechanism in BitTorrent. P2P video streaming systems can be affected by this issue too (Mol et al., 2008; Asioli et al., 2012). Generally, the incentive policies can be divided into encouraging, punitive or the combination of them.

Figure 5 The application areas of game theory in P2P video streaming



Scheduling in P2P video streaming systems can be considered from two viewpoints. Downstream peers should prioritise their required chunks and upstream ones should have a timing plan to respond to the received requests. Although, in push-based techniques this issue will be dimmed.

Figure 5 depicts the application areas of game theory in P2P video streaming.

3.3 Proposed solutions

The game theoretical solution to solve the mentioned P2P video streaming challenges can be considered in four categories as follows:

- using known games such as Stackelberg
- designing a new game
- using auctions and bargaining
- mechanism design.

Note that auction theory is a subset of mechanism design, but it is considered separately because of the plurality of approaches based on it. The outstanding examples of each category are discussed in the following.

3.3.1 Simple give-and-take game

Defining a static complete information game based on the upload bandwidth sharing is a simple but effective method for modelling the interaction between peers in a P2P video streaming system. As an obvious example, Asioli et al. (2012) present this form of modelling to deal with free riding. Equation (1) shows this model in a two-player game in the normal form that γ and λ are the gain and the loss parameters respectively. In other words, γ_i denotes the P_i download bandwidth and λ_i depicts the P_i upload bandwidth. Also, in game theory the i subscript on S stands for 'except i' (Osborne and Rubinstein, 1994). So, S_{-i} represents the strategy chosen by the opponent of i.

$$\begin{aligned} &N = \{1, 2\} \\ &S_i = \{1\ (Cooperate), 0\ (No\text{-}Cooperate)\} \\ &u_i = S_{-i}\gamma_i - S_i\lambda_i \end{aligned} \tag{1}$$

For better understanding, suppose that P_1 and P_2 play this game. If both of them choose Cooperate strategy then $\gamma_1 - \lambda_1$ and $\gamma_2 - \lambda_2$ represent the outcomes for P_1 and P_2 respectively. Alternatively, if P_1 chooses cooperate and P_2 selects no-cooperate, P_1 loses λ_1 and P_2 wins γ_2. Table 2 presents the game payoff matrix. The strategy profile (no-cooperate, no-cooperate) is a unique pure strategy Nash equilibrium (NE) for this game. Informally, a NE is a strategy profile in a game which there is no profitable deviation for all players in this situation (Narahari, 2014). Certainly this NE is not desirable to design a P2P system and is inconsistent with its goals. But if this game repeated finitely between two peers, the utility function is according to equation (2) (Asioli et al., 2012).

$$U_i(x) = \frac{\sum_{t=1}^{T_{fin}} u_i\left(S_1(t), S_2(t)\right)}{T_{fin}} \tag{2}$$

Figure 6 shows the possible NEs for repetition of this game. Note that, each intersection of concentric circles centred at the origin with the inner surface of convex shape can be an NE.

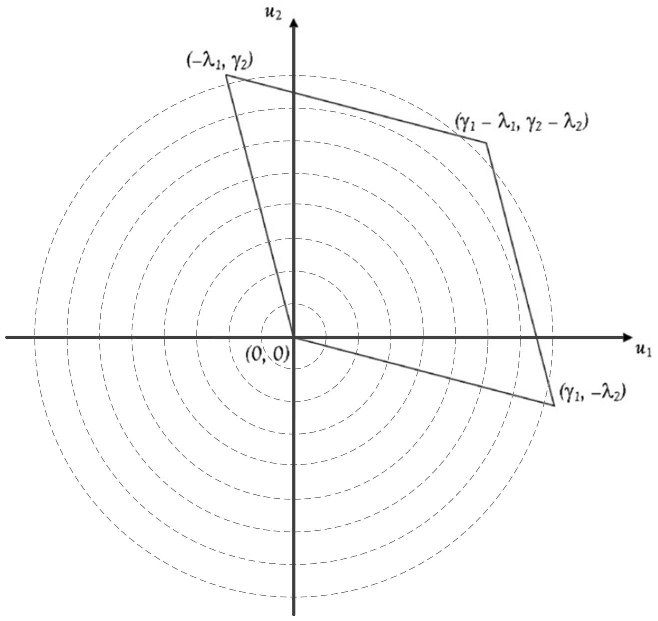
Table 2 Simple give-and-take game payoff matrix

P_1 \ P_2	*1 (Cooperative)*	*0 (No-Cooperative)*
1 (Cooperative)	$\gamma_1 - \lambda_1, \gamma_2 - \lambda_2$	$-\lambda_1, \gamma_2$
0 (No-Cooperative)	γ_1, λ_2	0, 0

The immediate acceptance request of a neighbour may be impossible in the case of multi-user scenarios. When a peer is supporting one of its neighbours, maybe it cannot supply another teammate. This problem is originated from considering a two-player game instead of a real n-player game. Asioli et al. (2012) proposed a credit-based mechanism to solve this problem. If $\chi_k^s(i,t)$ shows the number of uploaded chunks by P_i to P_k until t and $\chi_k^r(i,t)$ depicts the number of downloaded chunks from P_k by P_i, then, the difference between these two parameters should not exceed $\Delta^{\max}$. Equation (3) summarises this mechanism.

$$\begin{array}{l} \text{if } \chi_k^s(i,t) - \chi_k^r(i,t) \le \Delta^{\max} \text{ then } P_k \text{ is marked as cooperative by } P_i \\ \text{if } \chi_k^s(i,t) - \chi_k^r(i,t) > \Delta^{\max} \text{ then } P_k \text{ is marked as free-rider by } P_i \end{array} \tag{3}$$

Figure 6 Possible NEs in the finite repeated game



Also, authors have suggested a scheduling policy to prioritise the received requests. This policy decreases the delay and can be helpful to detect free riders. Deprivation and credit factors are two important definitions in this method. The deprivation factor of P_i which is shown by φ^i_{dep} determines the ratio between the missing chunks of P_i and the total number of the missing chunks of non-free rider P_i' neighbours. Equation (4) depicts this factor. Note, $\delta(P_i)$ shows the number of the missing chunks of P_i and N_i^* is the set of non-free rider neighbours of P_i.

$$\varphi^i_{dep} = \frac{\delta(P_i)}{\sum_{j \in N_i^*} \delta(P_j)} \tag{4}$$

Second factor is the credit which is shown by φ^i_{cr}. This factor is obtained from equation (5) and expresses the contribution received from another peer.

$$\varphi^i_{cr} = \frac{\max\left\{0,\ \chi^s_k(i,t) - \chi^r_k(i,t) + \Delta^{\max}\right\}}{\sum_{j \in N_k} \max\left\{0,\ \chi^s_k(j,t) - \chi^r_k(j,t) + \Delta^{\max}\right\}} \tag{5}$$

According to these factors and equation (3), Algorithm 1 can be presented to calculate the value of a received request from P_i which is shown by $S(r_i)$. Authors examined the effect of different values of (α, β) on the proposed mechanism in their experimental results (Asioli et al., 2012).

Algorithm 1 Optimal policy for delay minimisation and free-riding detection

function requestValueCalculation(request r_i)
    if $\chi^s_k(i,t) - \chi^r_k(i,t) > \Delta^{\max}$ **then**
        P_i is marked as a free rider
        $S(r_i) = -\infty$
    else
        if r_i is marked as a high priority **then**
            $S(r_i) = \alpha \cdot \varphi^i_{dep} + \beta \cdot \varphi^i_{cr}$ $\quad \triangleright\ \alpha + \beta = 1$
        else
            $S(r_i) = 0$
        enqueueBuffer(r_i)
    return $S(r_i)$

In spite of the discussed approach advantages to prevent free-riding dilemma, the calculation of these factors need the new common knowledge about the received and the missing chunks of all neighbours. So, this method suffers from traffic overhead and peers cheating possibility.

3.3.2 Auction-based approaches

Perhaps, auction is the most widely used approach in the game theoretical P2P video streaming researches. One example of such investigations can be found in Wu et al.

(2012). This research focuses on create incentive and optimal scheduling in P2P VoD application. Since peers interact together to supply a chunk in each round of auction, the bandwidth allocation is short-term in this scheme. The type of auction which is employed in this method is discriminative second price (Menezes and Monteiro, 2005). Also, the overlay network and demand management are mesh and pull respectively. Each peer must participate in the auctions and bids for desirable chunks. So, they need to budget which is implemented by a virtual currency protocol according to the proposed techniques in Vishnumurthy et al. (2003) and Turner and Ross (2004) or as based on simple credits in private BitTorrent (Liu et al., 2010). Sellers and bidders are two main elements in the auction. From the seller perspective, the proposed auction mechanism M is a triple (A, C, U) that A is the allocation rule, C is the charging scheme and U is the upload capacity contribution strategy. According to the allocation rule, at first, all received biddings are sorted in descending order, then the seller sells the maximum possible amount of its bandwidth based on the sorted list and its capacity. The charging scheme is exactly same as the second price auction. So, the winner must pay the second highest bid in the list. The market price in a round of auction for seller i which is indicated by $\tilde{p}_i$ is the highest losers' bid. Figure 7 shows the bidding and allocation example during two adjacent auctions. Note the proposed prices for each bidder and the number of allocated chunks for each seller depend on bidder's budget and the available upload bandwidth of seller respectively. The value of each missed chunk is determined by two factors: the proximity to playback index and the scarcity of available resources for this chunk. According to equation (6), the profit of a received chunk such as k from seller i for bidder j is equal to the difference between the value of k for $j(v_j^{(k)})$ and the price paid for it by j to $i(c_{ji}^{(k)})$.

$$U_{ji}^{(k)} = v_j^{(k)} - c_{ji}^{(k)} \tag{6}$$

In the first round of the auction, bidder has no idea for the minimum winner price of its desired chunks. So, he bids the value of these chunks exactly. But in the next rounds, it is possible that he corrects his bids. This procedure is called *truthful start with iterative price discovery strategy* by the authors.

Another auction-based P2P video streaming research is presented in Zou and Chen (2014). Bandwidth allocation, create incentive and scheduling are addressed in this research. Bidding in this scheme is a pair of proposed price and desired rate on the intended layer. In other words, there are M layers of video and bidder i bids $b_{ij}^m = (p_{ij}^m, r_{ij}^m)$ to seller j which means that i wants rate r on layer m from j. After receiving the bid, seller i allocates bandwidth x_{ij}^m to j based on his strategy. Authors proposed a credit-based mechanism to create incentive. Auction winners must pay their bids with the virtual currency. Seller rationality determines its goal in accordance with equation (7). E_m shows the neighbours of i in the overlay network of layer m.

$$\max \sum_{m \in M} \sum_{j:(i,j) \in E_m} \left(p_{ij}^m \cdot x_{ij}^m \right) \tag{7}$$

Also, the constraints in equation (8) must be satisfied by seller. Note, the upload bandwidth capacity of i is shown by C_i^u.

$$
\begin{aligned}
&1 \quad \sum_{m \in M} \sum_{j:(i,j) \in E_m} x_{ij}^m \le C_i^u, && \forall i \in V \\
&2 \quad 0 \le x_{ij}^m \le r_{ij}^m, && \forall j : (i, j) \in E_m, \forall m \in M.
\end{aligned} \tag{8}
$$

The seller i allocates $x_{ij}^m = \min(C_i^m, r_{ij}^m)$ bandwidth to the bidder with the highest bid. This procedure will continue until full up the upload bandwidth capacity of the seller or satisfy all demands. According to this mechanism and using scalable video codec (SVC) in this scheme the time sequence is divided into auctions and downloading parts and this sequence is repeated periodically. So, the bandwidth allocation of this scheme is medium term. The bidder rationality requires that equation (9) is satisfied under equation (10) constraints. Note, n_{ij}^m indicates the number of useful layers which i can provide to j, R_m shows the video rate of layer m and f_j is existing credit for j.

$$
\max gU_m\left(\sum_{i:(i,j)\in E_m} r_{ij}^m\right) - \sum_{i:(i,j)\in E_m} p_{ij}^m r_{ij}^m \tag{9}
$$

$$
\begin{aligned}
&1 \quad r_{ij}^m \le n_{ij}^m, \quad \forall i : (i, j) \in E_m \\
&2 \quad \sum_{i:(i,j)\in E_m} r_{ij}^m \le R_m \\
&3 \quad \sum_{i:(i,j)\in E_m} p_{ij}^m r_{ij}^m \le f_j.
\end{aligned} \tag{10}
$$

The proposed allocation and bidding processes are summarised in Algorithms 2 and 3 respectively.

Algorithm 2 Allocation process

function Allocation($b_{ij}^m = (p_{ij}^m, r_{ij}^m), \forall j : (i, j) \in E_m, \forall m \in M$)
  repeat
    Choose player j who submits the highest bid price p_{ij}^m among all the players.
    Allocate the bandwidth $x_{ij}^m = \min(C_i^u, r_{ij}^m)$ to player j.
  until $C_i^u = 0$ or $x_{ij}^m = r_{ij}^m$ for all the players.
return The assigned bandwidth x_{ij}^m to all the players.

Algorithm 3 Bidding process

function Bidding($x_i^m, \forall i : (i, j) \in E_m, \forall m \in M$)
  Bidding price initialisation:
    Initialise $p_{im}^m(0)$ to a small value, $\forall i : (i, j) \in E_m, \forall m \in M$
  Bidding price adjustment:
    for each peer i **do**
      if $r_{ij}^m > x_{ij}^m$ **then**

$p_{ij}^m = p_{ij}^m + \varepsilon$

else

$p_{ij}^m = P_{ij}^M$

Requested bandwidth calculation:

repeat

Find out supplying peer *i* who incurs the maximum marginal net utility.

$r_{ij}^m(t) = \min(n_{ij}^m \cdot r_m, [r_{ij}^m(t)^* / r_m] rm)$

Label the chunks requested from peer *i* as non-informative.

Deduct the credits to be paid to peer *i*.

Switch to the next neighbor with the current maximum marginal net utility.

until At least one following conditions will be satisfied

1 $f_j = 0$

2 $\sum_{i:(i,j) \in E_m} r_{ij}^m = R_m$

3 The last supplying peer has been requested

return $b_{ij}^m = (p_{ij}^m, r_{ij}^m)$

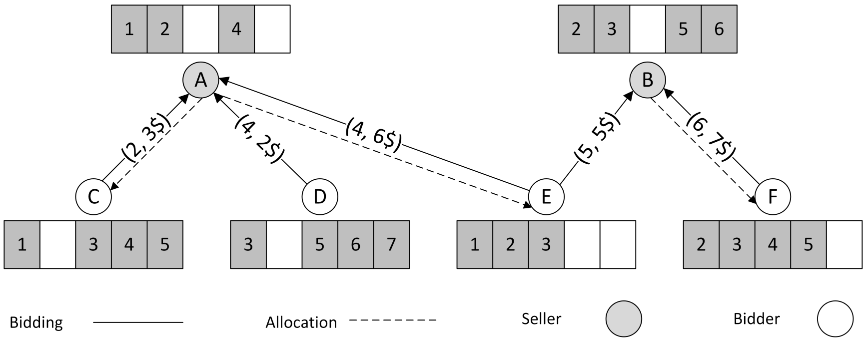
Sepidar is another auction-based live P2P video streaming which is based on the market mechanism and the gradient overlay network (Payberah et al., 2010). The overlay structure of this scheme is tree-based and each node which is more cooperative is more close to the video source. The distributed market model which is employed in Sepidar causes to decreasing the convergence time in the market mechanism according to the authors' claim. The children of a node, audit him for free-riding detection. Currency, price and cost are three important definitions in this system. The total number of upload slots which are allocated by a node (peer) is its currency. The price of a node is the minimum required currency to establish a connection with him. Finally, the distance between a node and the source of a stripe is called the cost of that node for this stripe. Note that, the video is divided into several stripes (sub-streams). So, the lowest cost node in the streaming tree of the specific stripe is the most desirable parent for enthusiasts to get this stripe. When all upload slots of a node such as *i* are allocated, the minimum currency of its children is the price of *i*. Sepidar mechanism is based on repeated upload slots auction to minimise the nodes cost. This mechanism can be described with the approximate auction algorithm which is a continuous and no reserve price auction. Therefore, the first bid for the upload slot is always winner. When all peer's upload slots are allocated, a new bid which is higher than the node price causes to child replacement. In this case, the orphaned child must find a new parent again. The employed mechanism in Sepidar is not the same as a normal auction from two points of view:

- First, in contrast with auction algorithms, there is no separated phase for bidding and downloading. For this reason, the mechanism is called continues auction.
- Second, the price of a upload slot will not be increased necessarily. If a peer is accused of free riding, its price will set to zero. So, this mechanism is called restartable auction.

Indeed, Sepidar provides a long-term bandwidth allocation in P2P video streaming.

In total, despite the very extensive use of auction-based approaches for P2P video streaming, these schemes can be suffered from extra control traffic and computation overhead.

Figure 7 The bidding and allocation example during two adjacent auctions in Wu et al. (2012)



3.3.3 Mechanism design for P2P video streaming

As previously discussed, mechanism design is reverse engineering of games. Of course, auction theory can be considered as a subset of mechanism design, but due to the extensive use of this approach in the P2P video streaming, it was evaluated separately. GaMe-PLive is a new *game theoretical mechanism for P2P live* video streaming (Mahini et al., 2016). This scheme is provided punitive mechanism for short-term bandwidth allocation that attempts to avoid control traffic and computational overheads. The proposed mechanism is based on a new non-cooperative static complete information game. Equation (11) shows this game in normal/strategic form. Each of two players of this game can choose *accept* or *reject* strategy. Also, $R_{ij}(t)$ and $N_{ij}(t)$ show the total number of rejection *j* by *i* and the total number of chunks which *j* can provide to *i* in time *t*, respectively. $\Delta(R_{ij}(t))$ shows the judgement of *j* in response to this question: what is the probability of *i* to be a free rider? Indeed, to avoid hasty judgement, the fuzzy behavioural function is employed. Based on the recent comments, this function is called risk factor from the responder perspective and endures function from the requester viewpoint. Figure 8 shows this function. Peer *j* believes that *i* is not a free rider until the total number of its rejected requests by *i* reaches to α. In the range of α to β this belief will be broken slowly and linearly. After passing $R_{ij}(t)$ through β threshold, peer *i* believes that *j* is a free rider. So, there are two important parts in the game payoff function. First, $S_{-i} - S_i$ which shows the outcome of the current trade-offs between two adjacent peers. Second, $\Delta(R_{ij}(t))(N_{ij}(t) - S_{-i}$ which indicates the endangered future needs of *i* that can be provided by j due to the risk of being accused of free riding.

$$
\begin{aligned}
&N = \{Peer_1, Peer_2\} \\
&S_i = \{Accept = 1, Reject = 0\} \\
&U_i = S_{-i} - S_i - \Delta\left(R_{ij}(t)\right)\left(N_{ij}(t) - S_{-i}\right)
\end{aligned}
\tag{11}
$$

In GaMe-PLive, it is proven that if $\alpha \geq \frac{\beta+1}{2}$ choosing *accept* is wisest or most prudent strategy in this game and with satisfying this condition the desired outcome will be achieved. Earliest rarest first is the scheduling strategy for requesting missed chunks in this mechanism. Also, the scheduling priority of responding to the received requests depends on the need of provider to requester. In other words, more need means sooner response. A specific definition is raised for peer cheating in this research. The dishonesty of peers to declare their assets is interpreted to peer cheating. In this scheme, cheating is not helpful to escape from participation for the cheaters. A false claim of having chunks by a peer leads to inability to respond to its neighbours requests and then it will be marked as a free rider. Also, hiding assets is not rational for a peer because due to decreasing the need of its neighbours to him, the priority of its requests will be decreased. In addition, accessing to the first copy of the video chunks holders list is possible via sending inquiry to the video server.

Figure 8 The endure function or risk factor in Mahini et al. (2016)

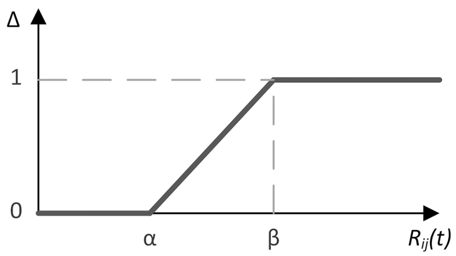
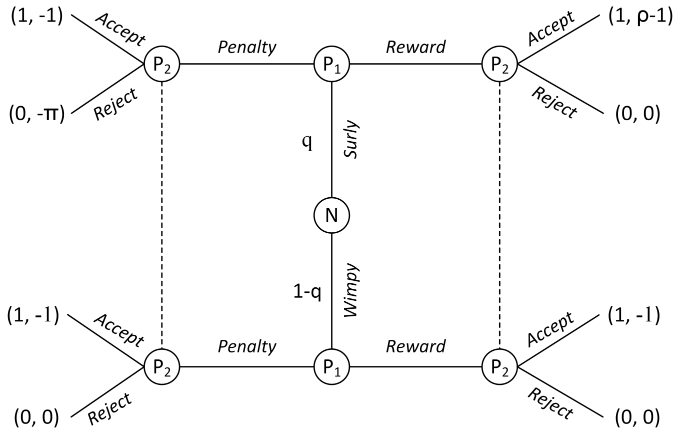


Figure 9 The proposed game in Mahini et al. (2017) which is inspired from Beer-Quiche game



Notes: Each peer can be a *Surly* player with probability q or a *Wimpy* with probability $1 - q$. Indeed, determining the type of each peer is on the shoulders of the nature node (N). The ρ and Π present the amount of rewards and penalties in the game respectively.

Table 3 Some famous game theoretical approaches to P2P video streaming

Name or authors	*Ref.*	*Game type*	*Comments*
Wu et al.	Wu et al. (2013)	Repeated Stackelberg	Encouraging mechanism for bandwidth allocation in P2P-VoD
Mostafavi et al.	Mostafavi and Dehghan (2015)	Stackelberg and reverse	Bandwidth allocation in live P2P streaming
Kang et al.	Kang and Wu (2013)	Stackelberg	Credit-based incentive mechanism
Kang et al.	Kang and Wu (2015)	Stackelberg	Credit-based incentive mechanism for heterogeneous network
Liu et al.	Liu et al. (2014)	Bargaining	Bandwidth allocation and incentive mechanism
Wu et al.	Wu et al. (2012)	Discriminative second price auction	Incentives and optimal scheduling
Chu et al.	Chu et al. (2009)	Auction	Bandwidth allocation for P2P VoD streaming using Network Coding
Sepidar	Payberah et al. (2010)	Continuous auction	Long-term bandwidth allocation in P2P live streaming
Zou et al.	Zou and Chen (2014)	Auction	Credit-based bandwidth allocation
SALSA	Kim et al. (2009)	Auction	Super-peer assisted live streaming architecture
GLive	Payberah et al. (2011)	Auction	Punitive, long-term bandwidth allocation in P2P live streaming
Guo et al.	Guo and Kwok (2011)	Auction	Bandwidth allocation for live P2P streaming
GaMe-PLive	Mahini et al. (2016)	Mechanism design	Short-term bandwidth allocation and punitive mechanism
Tian et al.	Tian et al. (2013)	Mechanism design	Dynamic adaptive P2P video streaming
Mahini et al.	Mahini et al. (2017)	Mechanism design	Peer-assisted video streaming based on NC and Beer-Quiche game
Asioli et al.	Asioli et al. (2012)	New static game	Short-term bandwidth allocation and punitive mechanism
Autotune	Lin and Shen (2015)	Non-cooperative Stackelberg	Bitrate adaptation for P2P assisted cloud-based VoD streaming

Another mechanism for P2P video streaming is presented in Mahini et al. *2017). This mechanism is based on a famous signalling game which is called Beer-Quiche. Indeed, Beer-Quiche is an incomplete information game which is presented in the extensive form. Figure 9 shows this game structure. This scheme motivates peers to cooperate with encouraging-punitive (hybrid) mechanism. *Surly* peers have the ability to pay reward or do penalty for other peers. In order to avoid from more overhead, this ability is not given to all peers. Indeed, encouraging all peers to participate with the minimum rewards and penalties is the strength of this mechanism. In these games, two types of perfect Bayesian Nash equilibria (PBE) are considered: separated and pooling (Fujiwara-Greve, 2015). In a separated PBE, each type of player chooses different action, so the types of players can be known by their actions. In contrast with separating, in a pooling PBE, all types of players choose the same action (strategy). So, in a pooling PBE, the type of player is not known by its action. Authors proof that if both ρ and Π are greater than 1, there is no separating PBE in this game. Also, they proof that if $q > \frac{1}{\rho}$ and $q > \frac{1}{\Pi}$, the *accept* is always the best response for P2. This scheme benefits from network coding (NC) and SVC too. In contrast with many recent game theoretical approaches, the game theory is used in the design time of this scheme and it does not impose any additional overhead at runtime. Not needing to periodically exchange the buffer mapping between peers is one the most important features in this research. Also, other control information is exchanged by piggybacking as same as GaMe-PLive. Lying in announcing assets by peers is interpreted to cheating. The proposed mechanism can eliminate cheating potential. Finally, authors provided new definition for fairness in the P2P video streaming system in this paper. They defined fairness as the balancing requests dispatching among all peers and also creating neighbour groups with balanced resources in the system. This mechanism could guarantee the fairness with the new interpretations as well.

3.3.4 Overview on other methods

Tian et al. (2013) design a mechanism for dynamic P2P video streaming. According to their claim, dynamic adaptive streaming over the internet has been one of the new trends in recent researches. In this type of streaming, the quality of received video dynamically changes based on the network conditions. They proposed a cooperative game to encourage peers for more participation. In fact, a peer with more cooperation receives the higher quality of video. In Mostafavi and Dehghan (2015), the Stackelberg game is employed for the shared bandwidth management in live P2P streaming. The proposed method uses additional mechanism based on reverse auction. These authors also proposed a method for matching sellers and buyers in shared bandwidth trading based on an auction mechanism in a helper-assisted approach (Mostafavi and Dehghan, 2016). Using the Stackelberg game can be viewed in Kang and Wu (2015) too. This research focuses on creating incentive in a heterogeneous P2P system. The agreement on the amount of bandwidth and the cost of payment is provided through the bargaining in this scheme. The double auction is employed in Feng et al. (2010) to prefetch the video in VoD P2P streaming. Taking advantage of cloud services along with game theory and combination with P2P systems has been very interesting in recent years. Autotune (Lin and Shen, 2015) is one of these systems, which employs the Stackelberg game for creating the adaptive bitrate in a peer-assisted VoD streaming. CLive (Payberah et al., 2012), CALMS

(Wang et al., 2012) and AngelCast (Sweha et al., 2012) are other famous peer-assisted cloud-based video streaming. Table 3 shows the summarisation of some game theoretical approaches to P2P video streaming.

4 Conclusions

Recent reports and forecasts indicate that the video applications consume the bulk internet traffic. Also, user expectations for watching high quality and uninterrupted video are growing every day. Using the P2P architecture instead of C/S is more helpful in this kind of circumstances to provide the required resources. But the complicity of management is an inherit challenge in P2P systems. The autonomy of self-interested peers leads to the desired goals of a P2P system not to be provided well. So, game theoretical approaches are very interested in analysing and designing these systems. In this paper, at first, the concepts of P2P video streaming were studied. Then, after presenting the game theory overview, some important game theoretical approaches to P2P video streaming were evaluated. Due to these studies, game theory can be helpful for P2P video streaming in three areas:

- bandwidth allocation
- create incentive
- optimal scheduling.

Also, four approaches are employed in these schemes:

- using the predefined classical games
- designing a new game to model and analyse the interaction between the existing entities
- taking advantage of the auction mechanisms
- mechanism design to propose a game with desired outcomes.

Although, effective game theoretical methods have been presented to address P2P video streaming demands, but with studying these schemes under scrutiny, it seems necessary to express a few points:

- Designers must strictly be careful about the negative effects of control data exchange and computational overheads. If the designed mechanism needs some frequently computations or periodically control data transmissions, the proposed method will fall into some serious challenges. Note, even if these computations and transmissions are very low, but their repetition can affect on the system performance. For example, in an auction-based short-term or medium-term bandwidth allocation, receiving the bids and making the decision are repeated frequently. So, the system suffers from extra overheads in such methods. The need for additional common knowledge to make a decision should be considered. Calculating the deprivation and the credit factors in Asioli et al. (2012) are the prominent examples for this issue. Also, in some long-term bandwidth allocation schemes which construct the overlay by an auction mechanism, the lack of enough attention to orphaned peers is very challenging. Take Sepidar as an example of this issue.

- Peer cheating is another important design issue. Peers' dishonesty in the declaration of their assets is interpreted as peer cheating. The methods which assume peers are always honest will face with some serious problems in practice.
- Fairness is an important research gap in this domain which has different interpretations. Making neighbourhood groups with equal resource availability and balanced request dispatching among peers are two examples of fairness which have not been mentioned enough in the researches.

Peer-assisted cloud-based video streaming is considered as a new trend for future work in this research domain. Also, multi-channel and dynamic adaptive streaming specially in mobile networks are prominent research areas which still need to be studied further.

References

Abboud, O., Pussep, K., Kovacevic, A., Mohr, K., Kaune, S. and Steinmetz, R. (2011) 'Enabling resilient P2P video streaming: survey and analysis', *Multimedia Systems*, Vol. 17, No. 3, pp.177–197.

Akamai (2016) *Delivery Network (CDN) & Cloud Computing Services*, Akamai [online] http://www.akamai.com/ (accessed 15 February 2016).

Alghazawy, B.A. and Fujita, S. (2011) 'Probabilistic packet scheduling scheme for hybrid pull-push P2P live streaming protocols', *Networking and Computing (ICNC), 2011 Second International Conference on*, pp.248–251, IEEE.

Annapureddy, S., Guha, S., Gkantsidis, C., Gunawardena, D. and Rodriguez, P.R. (2007) 'Is high-quality VoD feasible using P2P swarming?', *Proceedings of the 16th International Conference on World Wide Web*, pp.903–912, ACM.

Apostolopoulos, J.G., Tan, W-T. and Wee, S.J. (2002) *Video Streaming: Concepts, Algorithms, and Systems*, Report HPL-2002-260, HP Laboratories.

Asioli, S., Ramzan, N. and Izquierdo, E. (2012) 'A game theoretic approach to minimum-delay scalable video transmission over P2P', *Signal Processing: Image Communication*, Vol. 27, No. 5, pp.513–521.

Banerjee, S., Kommareddy, C., Kar, K., Bhattacharjee, B. and Khuller, S. (2003) 'Construction of an efficient overlay multicast infrastructure for real-time applications', *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications*, Vol. 2, IEEE, pp.1521–1531, IEEE Societies.

Bauso, D. (2016) *Game Theory with Engineering Applications: Advances in Design and Control*, SIAM, Philadelphia, PA, USA.

BitTorrent (2014) [online] http://www.bittorrent.com/ (accessed 6 April 2014).

Byun, H. and Lee, M. (2009) 'Hypo: a peer-to-peer based hybrid overlay structure', *Advanced Communication Technology, 2009. ICACT 2009. 11th International Conference on*, Vol. 1, pp.840–844, IEEE.

Castro, M., Druschel, P., Kermarrec, A-M., Nandi, A., Rowstron, A. and Singh, A. (2003) 'Splitstream: high-bandwidth multicast in cooperative environments', *ACM SIGOPS Operating Systems Review*, Vol. 37, No. 5, pp.298–313, ACM.

Chang, L. (n.d.) *A Survey on Modeling Peer-to-Peer Video Streaming Systems*, Technical Report V00687101, University of Victoria -Department of Computer Sciences.

Chu, X., Zhao, K., Li, Z. and Mahanti, A. (2009) 'Auction-based on-demand P2P min-cost media streaming with network coding', *IEEE Transactions on Parallel and Distributed Systems*, Vol. 20, No. 12, pp.1816–1829.

Chu, Y-H., Rao, S.G., Seshan, S. and Zhang, H. (2002) 'A case for end system multicast', *Selected Areas in Communications, IEEE Journal on*, Vol. 20, No. 8, pp.1456–1471.

Cisco (2015) *Cisco Visual Networking Index: Forecast and Methodology*, 2014–2019 white paper, Cisco [online] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html (accessed 15 January 2016).

Cisco (2016) *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update*, 2015–2020 white paper, Cisco [online] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html (accessed 15 January 2016).

ComScore (2013) *ComScore Releases March 2013 U.S. Online Video Rankings*, ComScore, Inc. [online] http://www.comscore.com/Insights/Press_Releases/2013/4/comScore_Releases_March_2013_US_Online_Video_Rankings (accessed 14 February 2014).

Conviva, The Team (2016) http://www.conviva.com/the-team/ (accessed 11 March 2016).

Cui, Y., Li, B. and Nahrstedt, K. (2004) 'oStream: asynchronous streaming multicast in application-layer overlay networks', *Selected Areas in Communications, IEEE Journal on*, Vol. 22, No. 1, pp.91–106.

Dan, A. and Sitaram, D. (1996) 'A generalized interval caching policy for mixed interactive and long video environments', *SPIE Multimedia Computing and Networking Conference*.

Dana, C., Li, D., Harrison, D. and Chuah, C.-N. (2005) 'Bass: BitTorrent assisted streaming system for video-on-demand', *Multimedia Signal Processing, 2005 IEEE 7th Workshop on*, pp.1–4, IEEE.

Deshpande, H., Bawa, M. and Garcia-Molina, H. (2008) *Streaming Live Media over a Peer-to-Peer Network*, Technical Report 501, 27 December, Stanford InfoLab.

Do, T.T., Hua, K.A. and Tantaoui, M.A. (2004) 'P2VoD: providing fault tolerant video-on-demand streaming in peer-to-peer environment', *Communications, 2004 IEEE International Conference on*, Vol. 3, pp.1467–1472, IEEE.

Feng, Y., Li, B. and Li, B. (2010) 'Peer-assisted VoD prefetching in double auction markets', *Network Protocols (ICNP), 2010 18th IEEE International Conference on*, pp.275–284, IEEE.

Fujiwara-Greve, T. (2015) *Non-Cooperative Game Theory*, Monographs in Mathematical Economics, Springer, Japan.

Gau, V., Wang, Y-H. and Hwang, J-N. (2008) 'A hierarchical push-pull scheme for peer-to-peer live streaming', *Circuits and Systems, 2008. ISCAS 2008. IEEE International Symposium on*, pp.2066–2069, IEEE.

Ghanbari, A., Rabiee, H.R., Khansari, M. and Salehi, M. (2012) 'PPM – a hybrid push-pull mesh-based peer-to-peer live video streaming protocol', *Computer Communications and Networks (ICCCN), 2012 21st International Conference on*, pp.1–8, IEEE.

Guo, D. and Kwok, Y-K. (2011) 'A new auction based approach to efficient P2P live streaming', *Parallel and Distributed Systems (ICPADS), 2011 IEEE 17th International Conference on*, pp.573–580, IEEE.

Guo, Y., Mathur, S., Ramaswamy, K., Yuy, S. and Patel, B. (2006) *Ponder: Providing Commercial-Quality Video-on-Demand Service Using Peer-to-Peer Network*, Technical report, Corporate Research, Thomson Inc.

Guo, Y., Suh, K., Kurose, J. and Towsley, D. (2003a) 'P2Cast: peer-to-peer patching scheme for VoD service', *Proceedings of the 12th International Conference on World Wide Web*, pp.301–309, ACM.

Guo, Y., Suh, K., Kurose, J. and Towsley, D. (2003b) 'A peer-to-peer on-demand streaming service and its performance evaluation', *Multimedia and Expo, 2003. ICME'03. Proceedings. 2003 International Conference on*, Vol. 2, p.649, IEEE.

Guo, Y., Suh, K., Kurose, J. and Towsley, D. (2008) 'DirectStream: a directory-based peer-to-peer video streaming service', *Computer Communications*, Vol. 31, No. 3, pp.520–536.

Huang, F., Ravindran, B. and Kumar, V.A. (2009) 'An approximation algorithm for minimum-delay peer-to-peer streaming', *Peer-to-Peer Computing, 2009. P2P'09. IEEE Ninth International Conference on*, pp.71–80, IEEE.

Hughes, D., Coulson, G. and Walkerdine, J. (2005) 'Free riding on Gnutella revisited: the bell tolls?', *Distributed Systems Online*, June, Vol. 6, No. 6, p.1, IEEE, DOI: 10.1109/MDSO.2005.31.

Kaashoek, M.F. and Douglis, F. (2001) 'Guest editors' introduction: scalable internet services', *IEEE Internet Computing*, Vol. 5, No. 4, pp.36–37.

Kang, X. and Wu, Y. (2013) 'A game-theoretic approach for cooperation stimulation in peer-to-peer streaming networks', *Communications (ICC), 2013 IEEE International Conference on*, pp.2283–2287, IEEE.

Kang, X. and Wu, Y. (2015) 'Incentive mechanism design for heterogeneous peer-to-peer networks: a Stackelberg game approach', *IEEE Transactions on Mobile Computing*, Vol. 14, No. 5, pp.1018–1030.

Kangasharju, J., Roberts, J. and Ross, K.W. (2002) 'Object replication strategies in content distribution networks', *Computer Communications*, Vol. 25, No. 4, pp.376–383.

Kim, J., Lee, Y. and Bahk, S. (2009) 'Salsa: super-peer assisted live streaming architecture', *2009 IEEE International Conference on Communications*, pp.1–5, IEEE.

Kostić, D., Rodriguez, A., Albrecht, J. and Vahdat, A. (2003) 'Bullet: high bandwidth data dissemination using an overlay mesh', *ACM SIGOPS Operating Systems Review*, Vol. 37, pp.282–297, ACM.

Kozamernik, F. (2002) 'Media streaming over the internet – an overview of delivery technologies', *EBU Technical Review*, October, No. 292.

Kurose, J. and Ross, K. (2012) *Computer Networking: A Top-Down Approach, Always Learning*, Pearson Education, Limited, USA.

Li, B. and Yin, H. (2007) 'Peer-to-peer live video streaming on the internet: issues, existing approaches, and challenges [peer-to-peer multimedia streaming]', *IEEE Communications Magazine*, Vol. 45, No. 6, pp.94–99.

Li, B., Xie, S., Qu, Y., Keung, G.Y., Lin, C., Liu, J. and Zhang, X. (2008) 'Inside the new CoolStreaming: principles, measurements and performance implications', *INFOCOM 2008. The 27th Conference on Computer Communications*, IEEE.

Liao, X., Jin, H., Liu, Y., Ni, L.M. and Deng, D. (2006) 'AnySee: peer-to-peer live streaming', *INFOCOM*, Vol. 25, pp.1–10, Citeseer.

Limelight (2016) *Limelight Networks: #1 Ranked CDN for Fast, Secure, Reliable Delivery* [online] http://www.limelight.com/ (accessed 15 February 2016).

Lin, Y. and Shen, H. (2015) 'Autotune: game-based adaptive bitrate streaming in P2P-assisted cloud-based VoD systems', *Peer-to-Peer Computing (P2P), 2015 IEEE International Conference on*, pp.1–10, IEEE.

Liu, J., Rao, S.G., Li, B. and Zhang, H. (2008a) 'Opportunities and challenges of peer-to-peer internet video broadcast', *Proceedings of the IEEE*, Vol. 96, No. 1, pp.11–24.

Liu, L., Zou, J. and Xiong, H. (2014) 'Bandwidth allocation for video streaming over peer-to-peer networks with Nash bargaining', *Proceedings of International Conference on Internet Multimedia Computing and Service*, p.363, ACM.

Liu, Y., Guo, Y. and Liang, C. (2008b) 'A survey on peer-to-peer video streaming systems', *Peer-to-Peer Networking and Applications*, Vol. 1, No. 1, pp.18–28.

Liu, Z., Dhungel, P., Wu, D., Zhang, C. and Ross, K.W. (2010) 'Understanding and improving ratio incentives in private communities', *Distributed Computing Systems (ICDCS), 2010 IEEE 30th International Conference on*, pp.610–621, IEEE.

Lo Cigno, R., Russo, A. and Carra, D. (2008) 'On some fundamental properties of P2P push/pull protocols', *Communications and Electronics, 2008. ICCE 2008. Second International Conference on*, pp.67–73, IEEE.

Lu, Y., Fallica, B., Kuipers, F.A., Kooij, R.E. and van Mieghem, P. (2009) 'Assessing the quality of experience of SopCast', *IJIPT*, Vol. 4, No. 1, pp.11–23.

Magharei, N. and Rejaie, R. (2009) 'Prime: peer-to-peer receiver-driven mesh-based streaming', *IEEE/ACM Transactions on Networking (TON)*, Vol. 17, No. 4, pp.1052–1065.

Magharei, N., Rejaie, R. and Guo, Y. (2007) 'Mesh or multiple-tree: a comparative study of live P2P streaming approaches', *INFOCOM 2007. 26th IEEE International Conference on Computer Communications*, pp.1424–1432, IEEE.

Mahini, H., Dehghan, M., Navidi, H. and Masoud Rahmani, A. (2016) 'GaMe-PLive: a new game theoretic mechanism for P2P live video streaming', *International Journal of Communication Systems*, Vol. 29, No. 6, pp.1187–1203.

Mahini, H., Dehghan, M., Navidi, H. and Rahmani, A.M. (2017) 'Peer-assisted video streaming based on network coding and beer-quiche game', *AEU-International Journal of Electronics and Communications*, Vol. 73, pp.34–45, ISSN: 1434-8411 [online] DOI: https://doi.org/10.1016/j.aeue.2016.12.022; http://www.sciencedirect.com/science/article/pii/S1434841116308512.

Marfia, G., Pau, G., Di Rico, P. and Gerla, M. (2007) 'P2P streaming systems: a survey and experiments', *Proceedings of the Streaming Day*.

Menezes, F. and Monteiro, P. (2005) *An Introduction to Auction Theory*, Oxford University Press.

Mol, J.J-D., Pouwelse, J.A., Meulpolder, M., Epema, D.H. and Sips, H.J. (2008) 'Give-to-Get: free-riding-resilient video-on-demand in P2P systems', *Proceeding of the 15th SPIE/ACM Multimedia Computing and Networking (MMCN'08)*.

Mostafavi, S. and Dehghan, M. (2015) 'Game theoretic bandwidth procurement mechanisms in live P2P streaming systems', *Multimedia Tools and Applications*, pp.1–24.

Mostafavi, S. and Dehghan, M. (2016) 'Game-theoretic auction design for bandwidth sharing in helper-assisted P2P streaming', *International Journal of Communication Systems*, Vol. 29, No. 6, pp.1057–1072.

Myerson, R. (2013) *Game Theory*, Harvard University Press, USA.

Narahari, Y. (2014) *Game Theory and Mechanism Design*, Vol. 4, World Scientific, Singapore.

Osborne, M.J. and Rubinstein, A. (1994) *A Course in Game Theory*, MIT Press, USA.

Pai, V., Kumar, K., Tamilmani, K., Sambamurthy, V. and Mohr, A.E. (2005) 'Chainsaw: eliminating trees from overlay multicast', *Peer-to-Peer Systems IV: 4th International Workshop, IPTPS 2005*, 24–25 February, pp.127–140, Ithaca, NY, USA, Revised Selected Papers, Springer Berlin Heidelberg, Berlin, Heidelberg, ISBN: 978-3-540-31906-1, DOI: 10.1007/11558989_12 [online] http://dx.doi.org/10.1007/11558989_12.

Pallis, G. and Vakali, A. (2006) 'Insight and perspectives for content delivery networks', *Communications of the ACM*, Vol. 49, No. 1, pp.101–106.

Pathan, A-M.K. and Buyya, R. (2007) *A Taxonomy and Survey of Content Delivery Networks*, Technical report, Grid Computing and Distributed Systems Laboratory, University of Melbourne.

Payberah, A.H., Dowling, J. and Haridi, S. (2011) 'Glive: the gradient overlay as a market maker for mesh-based P2P live streaming', *2011 10th International Symposium on Parallel and Distributed Computing*, pp.153–162, IEEE.

Payberah, A.H., Kavalionak, H., Kumaresan, V., Montresor, A. and Haridi, S. (2012) 'CLive: cloud-assisted P2P live streaming', *Peer-to-Peer Computing (P2P), 2012 IEEE 12th International Conference on*, pp.79–90, IEEE.

Payberah, A.H., Rahimian, F., Haridi, S. and Dowling, J. (2010) 'Sepidar: incentivized market-based P2P live streaming on the gradient overlay network', *Multimedia (ISM), 2010 IEEE International Symposium on*, pp.1–8, IEEE.

Project NICE at University of Maryland (2014) [online] http://www.cs.umd.edu/ projects/nice/ (accessed 11 March 2014).

Raake, A. and Egger, S. (2014) 'Quality and quality of experience', *Quality of Experience*, pp.11–33, Springer, Switzerland.

Ramaswamy, L. and Liu, L. (2003) 'Free riding: a new challenge to peer-to-peer file sharing systems', *System Sciences, 2003. Proceedings of the 36th Annual Hawaii International Conference on*, p.10, IEEE.

Shen, H., Li, Z. and Li, J. (2013) 'A DHT-aided chunk-driven overlay for scalable and efficient peer-to-peer live streaming', *Parallel and Distributed Systems, IEEE Transactions on*, Vol. 24, No. 11, pp.2125–2137.

SplitStream (2016) [online] http://research.microsoft.com/en-us/um/people/antr/SplitStream/ (accessed 10 May 2016).

Spoto, S., Gaeta, R., Grangetto, M. and Sereno, M. (2009) 'Analysis of PPLive through active and passive measurements', *Parallel & Distributed Processing, 2009. IPDPS 2009. IEEE International Symposium on*, pp.1–7, IEEE.

Sweha, R., Ishakian, V. and Bestavros, A. (2012) 'AngelCast: cloud-based peer-assisted live streaming using optimized multi-tree construction', *Proceedings of the 3rd Multimedia Systems Conference*, pp.191–202, ACM.

Tadelis, S. (2013) *Game Theory: An Introduction*, Princeton University Press, USA.

Teng, W-G. and Cheng, W-H. (2013) 'Exploiting scheduling and free-riding for offline downloading in BitTorrent networks', *International Journal of Communication Systems*, Vol. 26, No. 11, pp.1365–1374.

Thampi, S.M. (2013) *A Review on P2P Video Streaming*, arXiv preprint, arXiv:1304.1235.

The Stanford Peers Home Page (2016) [online] http://www-db.stanford.edu/peers (accessed 10 March 2016).

The State of the Art of P2P Video Streaming (n.d.) [online] http://www.cise.ufl.edu/~helal/classes/f10/notes/p2p-streaming-short-mcomp.pptx (accessed 19 September 2014).

Tian, G., Xu, Y., Liu, Y. and Ross, K. (2013) 'Mechanism design for dynamic P2P streaming', *Peer-to-Peer Computing (P2P), 2013 IEEE Thirteenth International Conference on*, pp.1–10, IEEE.

Tran, D.A., Hua, K.A. and Do, T. (2003) 'Zigzag: an efficient peer-to-peer scheme for media streaming', *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications*, Vol. 2, pp.1283–1292, IEEE Societies.

Turner, D.A. and Ross, K.W. (2004) 'A lightweight currency paradigm for the P2P resource market', *Proc. Electronic Commerce Research*.

Vakali, A. and Pallis, G. (2003) 'Content delivery networks: status and trends', *Internet Computing*, Vol. 7, No. 6, pp.68–74, IEEE.

Vandalore, B., Feng, W-C., Jain, R. and Fahmy, S. (2001) 'A survey of application layer techniques for adaptive streaming of multimedia', *Real-Time Imaging*, Vol. 7, No. 3, pp.221–235.

Venkataraman, V., Yoshida, K. and Francis, P. (2006) 'Chunkyspread: heterogeneous unstructured tree-based peer-to-peer multicast', *Network Protocols, 2006. ICNP'06. Proceedings of the 2006 14th IEEE International Conference on*, pp.2–11, IEEE.

Vishnumurthy, V., Chandrakumar, S. and Sirer, E.G. (2003) 'Karma: a secure economic framework for peer-to-peer resource sharing', *Workshop on Economics of Peer-to-Peer Systems*, Vol. 35.

Vlavianos, A., Iliofotou, M. and Faloutsos, M. (2006) 'Bitos: enhancing BitTorrent for supporting streaming applications', *INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, pp.1–6, IEEE.

Wang, F., Liu, J. and Chen, M. (2012) 'Calms: cloud-assisted live media streaming for globalized demands with time/region diversities', *INFOCOM, 2012 Proceedings IEEE*, pp.199–207, IEEE.

Wang, F., Liu, J. and Xiong, Y. (2008) 'Stable peers: existence, importance, and application in peer-to-peer live video streaming', *INFOCOM 2008. The 27th Conference on Computer Communications*, IEEE.

Wang, F., Xiong, Y. and Liu, J. (2007) 'mTreebone: a hybrid tree/mesh overlay for application-layer live video multicast', *Distributed Computing Systems, 2007. ICDCS'07. 27th International Conference on*, p.49, IEEE.

Wang, F., Xiong, Y. and Liu, J. (2010a) 'mTreebone: a collaborative tree-mesh overlay network for multicast video streaming', *Parallel and Distributed Systems, IEEE Transactions on*, Vol. 21, No. 3, pp.379–392.

Wang, M., Xu, L. and Ramamurthy, B. (2010b) 'Linear programming models for multichannel P2P streaming systems', *INFOCOM, 2010 Proceedings IEEE*, pp.1–5, IEEE.

Wen, G., Longshe, H. and Qiang, F. (2006) 'Recent advances in peer-to-peer media streaming systems', *China Communications*, Vol. 10, pp.52–57.

Wu, C., Li, Z., Qiu, X. and Lau, F. (2012) 'Auction-based P2P VoD streaming: incentives and optimal scheduling', *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, Vol. 8, No. 1S, p.14.

Wu, W., Lui, J.C. and Ma, R.T. (2013) 'On incentivizing upload capacity in P2P-VoD systems: design, analysis and evaluation', *Computer Networks*, Vol. 57, No. 7, pp.1674–1688.

Zhang, M., Luo, J-G., Zhao, L. and Yang, S-Q. (2005a) 'A peer-to-peer network for live media streaming using a push-pull approach', *Proceedings of the 13th Annual ACM International Conference on Multimedia*, pp.287–290, ACM.

Zhang, X. and Hassanein, H. (2012) 'A survey of peer-to-peer live video streaming schemes – an algorithmic perspective', *Computer Networks*, Vol. 56, No. 15, pp.3548–3579.

Zhang, X., Liu, J., Li, B. and Yum, T-S.P. (2005b) 'CoolStreaming/DONet: a data-driven overlay network for peer-to-peer live media streaming', *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies, Proceedings IEEE*, Vol. 3, pp.2102–2111, IEEE.

Zhao, L., Luo, J-G., Zhang, M., Fu, W-J., Luo, J., Zhang, Y-F. and Yang, S-Q. (2005) 'Gridmedia: a practical peer-to-peer based live video streaming system', *Multimedia Signal Processing, 2005 IEEE 7th Workshop on*, pp.1–4, IEEE.

Zou, J. and Chen, L. (2014) 'Joint bandwidth allocation, data scheduling and incentives for scalable video streaming over peer-to-peer networks', *Multimedia Tools and Applications*, Vol. 73, No. 3, pp.1269–1289.