Coalition based Multimedia Peer Matching Strategies for P2P Networks

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ABSTRACT

In this paper, we consider the problem of matching users for multimedia transmission in peer-to-peer (P2P) networks and identify strategies for fair resource division among the matched multimedia peers. We propose a framework for coalition formation, which enables users to form a group of matched peers where they can interact cooperatively and negotiate resources based on their satisfaction with the coalition, determined by explicitly considering the peer's multimedia attributes. In addition, our proposed approach goes a step further by introducing the concept of marginal contribution, which is the value improvement of the coalition induced by an incoming peer. We show that the best way for a peer to select a coalition is to choose the coalition that provides the largest division of marginal contribution given a deployed value-division scheme. Moreover, we model the utility function by explicitly considering each peer's attributes as well as the cost for uploading content. To quantify the benefit that users derive from a coalition, we define the value of a coalition based on the total utility that all peers can achieve jointly in the coalition. Based on this definition of the coalition value, we use an axiomatic bargaining solution in order to fairly negotiate the value division of the upload bandwidth given each peer's attributes.

Keywords: P eer-to-peer (P2P) network, multimedia P2P, peer-matching algorithm, coalition value, proportional bargaining solution.

1. INTRODUCTION

P2P multimedia applications (e.g.,[1–3]) have become increasingly popular and represent a large majority of the traffic over the current Internet. One of the unique aspects of P2P networks stems from its flexible and distributed nature, where each peer can act as both server (e.g., seeder) and client (e.g., leecher), i.e., providing one peer's contents to other peers, while simultaneously receiving other peers' contents.[4] This characteristic of P2P networks makes them particularly desirable for multimedia streaming to generate and distribute multimedia content (e.g.,[5–10]). While the above mentioned multimedia streaming systems over P2P networks have been successfully developed, the focus of P2P for multimedia is on developing efficient streaming solutions, and not on determining how peers should collaborate.

Alternatively, a general file sharing application such as BitTorrent[11] can be deployed for multimedia content sharing, while providing solutions for peer selection strategies as well as addressing the problem of free-riding. BitTorrent systems deploy a *tit-for-tat* algorithm (or *choking* algorithm) to select the peers with which they want to exchange files.[11,12] Based on this algorithm, a peer only considers the contributed upload rates of the other peers. Then, it selects a fixed number of peers that provide the highest upload rates to it, and in return, it uploads its content to these contributing peers.[11] While this algorithm favors peers with high upload rates, it does not consider the exact upload rates which a specific peer derives from its matching peers, as it implicitly assumes that there is no reluctance for peers to provide their entire upload bandwidth. Moreover, as this algorithm has been developed for sharing a general single content file (e.g., Linux software package), it does not efficiently consider the simultaneous sharing of multiple multimedia files and does not consider the availability or preferences of the peers for certain multimedia content. Hence, this tit-for-tat algorithm does not reflect the reciprocal behavior of peers. Self-interested multimedia peers would like to derive higher multimedia

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quality by downloading at high rates while uploading their content at lower rates, as the upload bandwidth is the most precious resource of a peer[13] and can be used to establish additional connections to other peers.

In this paper, we develop a solution for matching peers that is complementary to the aforementioned approaches, and can be used to form the alliances (connections) between peers. We consider the peers' satisfaction induced by the achieved quality and the peers' penalty due to the cost for content sharing. The other major aspect of P2P networks is that their survival depends on the contributions (i.e., shared upload bandwidth and content) of peers. Hence, peers in P2P networks need to decide how much upload bandwidth should be shared with other peers and with which peers they want to associate themselves. Therefore, we can model this problem as a *game* with autonomous and rational *players*, each having the goal to achieve a higher *utility*.

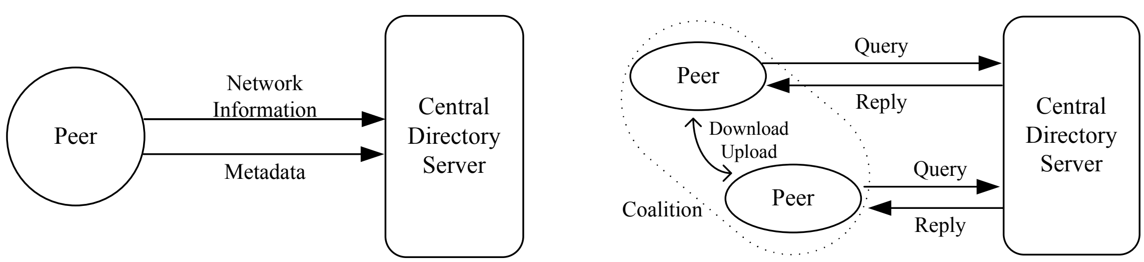
We focus on the *cooperative* interactions of peers. The cooperation in P2P networks has been discussed in the literature (see e.g.,[14,15]). To study the cooperative behavior of peers, we deploy coalition game theory[16] in order to design a peer matching policy by explicitly considering the peers' multimedia characteristics and available resources as well as the characteristics of P2P networks. In the coalition game theory, players cooperate with other players and make coalitions to achieve higher *values* in terms of the commonly achieved utility. The participating players will eventually benefit from fairly dividing the value, which is achieved by the coalition, among themselves. Hence, we propose a framework in which peers form coalitions and negotiate how to divide the achieved utility by the coalition. For a fair division of the value, we use a well-suited proportional bargaining solution (PBS)[17] that can successfully model the unique features of multimedia transmission over P2P networks. Note that the proposed peer matching policy can also enable us to implement a system that prevents the problem of free-riding.

This paper is organized as follows. In Section 2, we propose a framework for multimedia transmission over the P2P network and abstract a peer's attributes. Then, we define a utility function and discuss the cooperative behavior based on the achievable utilities. In Section 3, we model this problem as a coalition game and provide an algorithm that describes how to form coalitions. Then, we use axiomatic bargaining solutions as a tool for value-division. Simulation results are provided in Section 4 and conclusions are drawn in Section 5.

2. MODELS FOR P2P MULTIMEDIA USERS

2.1 System Model

We assume that the investigated P2P network in this paper is a type of overlay hybrid decentralized system model,[4] where all peers in a network are connected to a central directory server which holds all the network information of registered peers (e.g., Internet protocol (IP) address, connection bandwidth, etc.) as well as the available content information (e.g., files, multimedia content, etc.). The central directory server updates the above mentioned information and provides it for peers which request it in order to join a coalition. Peers then make use of this information to associate themselves with each other in order to exchange multimedia content. A typical hybrid decentralized P2P architecture is shown in Fig. 1.



(a) Registering Process (b) Interacting Process

Figure 1. An architecture of hybrid decentralized P2P network.

In P2P networks, since the upload bandwidth (rate) is the most precious resource,[13] the peers incur a cost by contributing their upload bandwidth to other peers. However, the contributed upload bandwidth is the only resource that can improve other peers' utility. To resolve this conflict, peers interact by adjusting their upload bandwidth. Hence, it is essential for a peer to select other peers with which it can cooperatively interact, and make coalitions. Then, the peers in a coalition achieve a common utility, called the value of a coalition, and they fairly divide the coalition value based on their contributions to the value. The proposed framework based on the overlay hybrid decentralized P2P system is portrayed in Fig. 2.

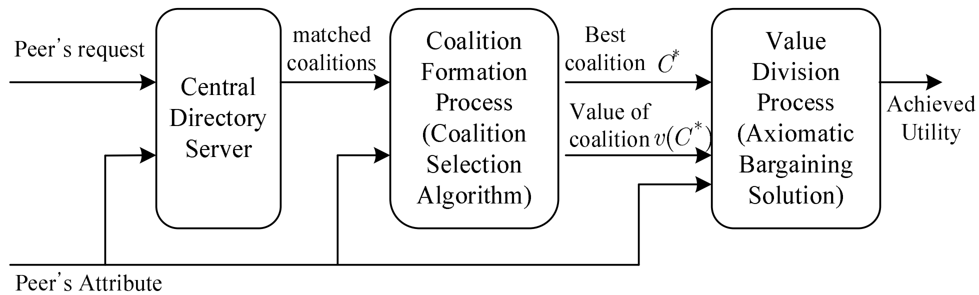


Figure 2. The proposed framework for multimedia transmission over an overlay hybrid decentralized P2P network.

2.2 Peer Modeling

The peers in a P2P network can be characterized by their possession and demands,[13,18] their content popularity and preference,[19,20] available bandwidth[13,21] as well as the cost for upload.[13,18] Moreover, a minimum download rate for a demanded multimedia content is required to successfully decode the content.[22] Hence, we abstract the attributes of peer i as

$$\mathbf{A}_i = \{\mathbf{P}_i, \mathbf{D}_i, \mathbf{p}_i^P, \mathbf{p}_i^D, L_i^D, L_i^U, \mathbf{R}_{\mathbf{D}_i}^{req}, c_i\}. \tag{1}$$

$\mathbf{P}_i$ and $\mathbf{D}_i$ denote *possessed* and *demanded* multimedia content of peer i, where $\mathbf{P}_i = \{P_{i1}, \ldots, P_{i|\mathbf{P}_i|}\}$ and $\mathbf{D}_i = \{D_{i1}, \ldots, D_{i|\mathbf{D}_i|}\}$ are the set of possessed and demanded multimedia content ordered by peer i's *popularity factor* p_{ij}^P on the jth possessed content $P_{ij} \in \mathbf{P}_i$ and *preference factor* p_{ik}^D on the kth demanded content $D_{ik} \in \mathbf{D}_i$. They are assumed to be characterized as $\sum_{j=1}^{|\mathbf{P}_i|} p_{ij}^P = 1$ and $\sum_{k=1}^{|\mathbf{D}_i|} p_{ik}^D = 1$ for $0 \leq p_{ij}^P, p_{ik}^D \leq 1$, respectively. The preference factors denote the preferences on demanded content, which are defined as

$$p_{ik_1}^D \geq p_{ik_2}^D \;\Leftrightarrow\; D_{ik_1} \succeq D_{ik_2} \text{ for } D_{ik_1}, D_{ik_2} \in \mathbf{D}_i, \tag{2}$$

where $D_{ik_1} \succeq D_{ik_2}$ denotes that peer i prefers the content D_{ik_1} to D_{ik_2}. Hence, $p_{i1}^D \geq p_{i2}^D \geq \cdots \geq p_{i|\mathbf{D}_i|}^D$ for all i. L_i^D and L_i^U represent the maximum *download* and *upload* bandwidth of peer i, which is typically $L_i^U \leq L_i^D$. In this P2P network, we assume that peers are trying to download content from other peers in the order of their preference factors. Hence, we can define the matched peers based on their content as well as their preferences.

Definition 2.1 (Matched Peers). *In a P2P network, any two peers m and n are* matched *if $D_{mj} \in \mathbf{P}_n$ and $D_{nk} \in \mathbf{P}_m$ for $D_{mj} \in \mathbf{D}_m$ and $D_{nk} \in \mathbf{D}_n$.*

Finally, the minimum rates $R_{D_{ik}}^{req} \in \mathbf{R}_{\mathbf{D}_i}^{req}$ for the downloaded multimedia content D_{ik} are required to successfully decode it. If this condition is not satisfied, a peer cannot decode the downloaded multimedia content, achieving no *utility*. c_i is the unit of the cost for upload rates. We will discuss the utility concept and define the utility function in the following section.

2.3 Utility based Peers' Cooperative Interactions

In this paper, it is assumed that one peer's utility improves as it can download its desired content at an increased multimedia quality and it decreases due to the cost for uploading its multimedia content to other peers.[13] Specifically, $Q(R)$ represents the achieved quality given the allocated rate R for multimedia applications.[22] Hence, we define the utility function of peer i, which is downloading the demanded content D_{ik} at rate $R_{D_{ik}}$ and providing upload rate R_{U_i} to other peers as:

$$U_i(R_{D_{ik}}, R_{U_i}) = \begin{cases} 0, & \text{if } R_{D_{ik}} < R_{D_{ik}}^{req}, \\ p_{ik} Q_i(R_{D_{ik}}) - c_i R_{U_i}, & \text{otherwise,} \end{cases} \tag{3}$$

where p_{ik} denotes the preference factor of peer i on the multimedia content $D_{ik} \in \mathbf{D}_i$ and a non-negative constant $R_{D_{ik}}^{req}$ represents the specific minimum required rates to decode the video sequence.

Based on the definition of utility, we analyze the cooperative interactions of peers sharing multimedia content in a P2P network. Since an incoming peer interacts with several matched peers in a coalition, we focus on a general one-to-many peers' interaction. Let $C_1 = \{1, \ldots, N\}$ be the coalition of peer 1 with its $(N-1)$ matched peers. Since peer 1 focuses on downloading its most desired content, while sharing its possessed content $\mathbf{P}_1$, the utilities of the peers in the coalition are expressed as

$$U_1 = p_{11} Q_1 \left(\sum_{i \in C_1 \backslash \{1\}} R_{U_{i1}} \right) - c_1 \left(\sum_{i \in C_1 \backslash \{1\}} R_{U_{1i}} \right), \tag{4}$$

$$U_i = p_{ij} Q_i \left(R_{U_{1i}} + \sum_{l \in C_i \backslash \{1,i\}} R_{U_{li}} \right) - c_i \left(R_{U_{i1}} + \sum_{l \in C_i \backslash \{1,i\}} R_{U_{il}} \right), \text{ for all } i \in C_1 \backslash \{1\}, \tag{5}$$

where p_{ij} denotes the preference factor of peer i on the jth demanded content $D_{ij} \in \mathbf{P}_1$, and $R_{U_{1i}} (\geq R_{D_{ij}}^{req})$ denotes the upload rate of peer 1 to peer i. The expression of $B \backslash A$ for two sets represents the relative complement of A in B. Since peer i is associated with peer 1 as well as other peers in its coalition C_i, the achieved utility of peer i depends on the upload rates $R_{U_{1i}}$ provided by peer 1 and $R_{U_{li}}$ provided by the other peers $l \in C_i \backslash \{1, i\}$. It also depends on the provided upload rates from peer i to the associated peers. We assume that peer i sustains its already established connections and provides only the remaining upload bandwidth to peer 1.

Since every peer needs to achieve at least a minimum utility (i.e., zero utility), (4) and (5) can be rewritten as

$$R_{U_{i1}} \geq \max \left\{ R_{D_{11}}^{req}, Q_1^{-1} \left(\frac{c_1 \left(\sum_{l \in C_1 \backslash \{1\}} R_{U_{1l}} \right)}{p_{11}} \right) \right\} - \sum_{l \in C_1 \backslash \{1,i\}} R_{U_{l1}}, \tag{6}$$

$$R_{U_{i1}} \leq \frac{p_{ij} Q_i (R_{U_{1i}} + \sum_{l \in C_i \backslash \{1,i\}} R_{U_{li}})}{c_i} - \sum_{l \in C_i \backslash \{1,i\}} R_{U_{il}} \triangleq R_{U_{i1}}^{MAX}, \tag{7}$$

for all $i \in C_1 \backslash \{1\}$. (6) can be expressed using $R_{U_{i1}}^{MAX}$ in (7) as

$$R_{U_{i1}} \geq \max \left\{ R_{D_{11}}^{req}, Q_1^{-1} \left(\frac{c_1 \left(\sum_{l \in C_1 \backslash \{1\}} R_{U_{1l}} \right)}{p_{11}} \right) \right\} - \sum_{l \in C_1 \backslash \{1,i\}} R_{U_{l1}}^{MAX} \triangleq R_{U_{i1}}^{min} \tag{8}$$

Therefore, the upload rate $R_{U_{i1}}$ can be expressed as

$$R_{U_{i1}} = \theta_i \cdot R_{U_{i1}}^{min} + (1 - \theta_i) \cdot R_{U_{i1}}^{MAX}, \tag{9}$$

with variable θ_i $(0 \leq \theta_i \leq 1)$. Note that $R_{U_{i1}}^{MAX}$ is a function of upload rates $R_{U_{1i}}$ from peer 1 to peer i and parameters of peer i in coalition C_i (i.e., upload/download rates in its coalition C_i). $R_{U_{i1}}^{min}$ is also a function of upload rates $R_{U_{1l}}$, $l \in C_1 \backslash \{1\}$ from peer 1 to its peers in coalition C_1, and coalition parameters of peer l, $l \in C_1 \backslash \{1\}$. Therefore, by substituting (9) into (4) and (5), the achievable utilities in coalition C_1 can be expressed as a function of peer 1's upload rates to its coalition peers given the other coalition parameters.

Hence, it can be concluded that if the feasible upload rate pairs satisfying (7) and (8) can be found, the peers' cooperative behavior finally benefits all the participating peers in this cooperative interaction. Therefore, it is essential for peers to form coalitions that enable peers to interact with each other cooperatively. The remaining question is hence how to negotiate an agreement for determining the upload rates of all peers after making a coalition (i.e., determining θ of each peer). In the following sections, we resolve this problem based on the game-theoretic approach from axiomatic bargaining theory by mapping this problem to a bargaining set-up with N players.

3. VALUE BASED COALITION FORMATION

3.1 Coalition Game Modeling

In this section, we describe how the interactions of peers in a P2P network can be formulated and modeled based on the coalition game. A *coalition game* consists of a finite set $\mathbf{N}$ (the set of N peers) and a function v that associates a real number $v(C)$ (the worth of C) with every nonempty subset C of $\mathbf{N}$ (a coalition).[16] For each coalition C, the value $v(C)$ is the total utility that can be obtained by cooperative interactions of coalition peers and is available for division among them. We define the value of a coalition C as

$$v(C) = \sum_{i \in C} U_i(R_{D_{ik}}, R_{U_i}), \tag{10}$$

where $R_{U_i} \in \{R_{U_i} | 0 \leq R_{U_i} \leq L_i^U\}$ and $R_{D_{ik}}$ are feasible upload rate and download rates for the content D_{ik}, respectively, and they are results of each peer's cooperative interactions with other peers. The basic idea of this definition is that peers will eventually benefit by making the coalition, which is obvious for peers in this P2P network because peers can obtain utilities only by being associated with other peers and sharing their possessed multimedia content.

Since the value of a coalition is defined as the total achievable utility in the coalition, the value increases only when matched peers join the coalition and the peers interact with each other cooperatively. This peer-matching mechanism is implemented based on the concept of *marginal contribution*.[16] The marginal contribution of peer i to any coalition C with $i \notin C$ is given by

$$\Delta v_i(C) = v(C \cup \{i\}) - v(C). \tag{11}$$

Hence, the marginal contribution represents the coalition value improvement as peers join the coalition. Thus, free-riders, for instance, obtain no utility since they are not matched with coalition peers and obtain no available bandwidth for downloading their desired content (i.e., they cannot join a coalition as their marginal contributions are not positive).

Note that we assume that if an incoming peer joins a coalition, this does not decrease the achievable utilities of the coalition peers already located in the coalition, since only the remaining upload bandwidth of the peers can be used to negotiate with the incoming peer. If there is not enough residual upload bandwidth to negotiate, this coalition is *infeasible* and a peer will not join this coalition. The process for the value-based coalition formation is summarized as follows.

1. *Initialization*: A peer requests the information about the coalitions of matched peers from the central directory server. Then, the peer obtains the set of coalitions $\mathbf{C}$.

2. *Feasibility Check*: A peer examines the existing coalitions $\mathbf{C}$ to which the peer is interested to cooperate and computes the feasible set of coalitions $\mathbf{C}_F$.

3. *Coalition Selection Process*: The peer selects the coalition C^* that can provide the highest utility among the feasible coalitions.

4. *Join a Coalition*: The peer joins coalition C^*.

3.2 PBS based Coalition Value Division

In this section, we deploy the PBS[17] to divide the commonly achieved utility of a coalition to its members fairly and optimally.

Definition 3.1 (PBS). *A function F is the PBS if there are strictly positive constants $p_1, \ldots, p_N$ such that for every feasible utility set $\mathbf{S}$ and the minimum utility point $\mathbf{d}^*$,*

$$F(\mathbf{S}, \mathbf{d}) = \lambda(\mathbf{S}, \mathbf{d})\mathbf{p},$$

where $\mathbf{p} = (p_1, \ldots, p_N)$ and $\lambda(\mathbf{S}, \mathbf{d}) = \max\{t \mid \mathbf{d} + t\mathbf{p} \in \mathbf{S}\}$.

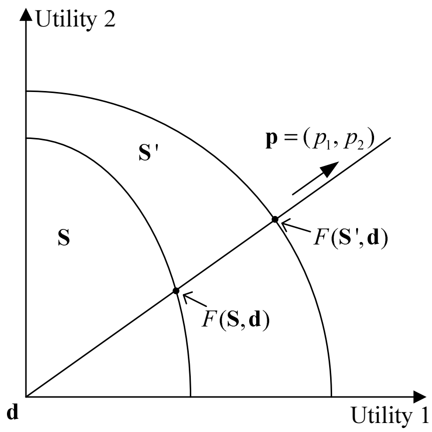


Figure 3. An illustrative example for PBS. PBSs of two peers with $\mathbf{p} = (p_1, p_2)$ in two different feasible utility sets $\mathbf{S}'$ and $\mathbf{S}$, where $\mathbf{S} \subset \mathbf{S}'$, are illustrated.

In this paper, the vector $\mathbf{p}$ is called the *inter-peer utility comparison ratio vector*. An illustrative example for PBS is shown in Fig. 3

To model the problem as a bargaining problem, the feasible utility set $\mathbf{S}$ and the disagreement point $\mathbf{d}$ need to be identified. First, the disagreement point is the zero utility, $\mathbf{d} = \mathbf{0}$. Moreover, a feasible utility set $\mathbf{S} \subset \mathbb{R}^N$ is the set of all the utility points that can be obtained by the cooperative interactions for the upload rates. For this analysis, we assume that peer 1 interacts with the other $(N-1)$ peers in its coalition C_1. Thus, the feasible utility set $\mathbf{S}$ can be expressed as

$$\mathbf{S} = \left\{ \left(U_1 \left(\sum_{l=2}^{N} R_{U_{l1}}, \sum_{l=2}^{N} R_{U_{1l}} \right), \mathbf{U} \right) \middle| R_{U_{1l}} \in \mathbf{R}_{U_{1l}}, R_{U_{l1}} \in \mathbf{R}_{U_{l1}}, \forall l \right\}, \tag{12}$$

where $\mathbf{R}_{U_{1l}} = \{R_{U_{1l}} | 0 \le R_{U_{1l}} \le L_1^U, \sum_{l \in C_1} R_{U_{1l}} \le L_1^U\}$, $\mathbf{R}_{U_{l1}} = \{R_{U_{l1}} | 0 \le R_{U_{l1}} \le L_l^U, R_{U_{l1}} + \sum_{h \in C_l} R_{U_{lh}} \le L_l^U\}$ for all l $(2 \le l \le N)$, and

$$\mathbf{U} = \left[U_2 \left(R_{U_{12}} + \sum_{l \in C_2 \setminus \{2\}} R_{U_{l2}}, R_{U_{21}} + \sum_{l \in C_2 \setminus \{2\}} R_{U_{2l}} \right), \ldots, \right.$$
$$\left. U_N \left(R_{U_{1N}} + \sum_{l \in C_N \setminus \{N\}} R_{U_{lN}}, R_{U_{N1}} + \sum_{l \in C_N \setminus \{N\}} R_{U_{Nl}} \right) \right]. \tag{13}$$

Since the solution needs to be optimal (in the sense of Pareto optimal) and yield higher utilities than the disagreement point, a set $\mathbf{B} \subseteq \mathbf{S}$, called bargaining set, can be constructed by cooperative behavior of peers. Hence,

$$\mathbf{B} = \left\{ \partial \mathbf{S} \cap \left\{ \mathbf{X} \mid \mathbf{X} \ge \mathbf{d} \text{ for all } \mathbf{X} \in \mathbb{R}^N \right\} \right\}, \tag{14}$$

where $\partial \mathbf{S}$ denotes the boundary[17] of the feasible utility set $\mathbf{S}$. The inter-peer utility comparison ratio vector $\mathbf{p}$ can be defined based on coalition peers' contributions to a coalition as it represents the weight of incentives for their contributions. For example, if the popularity of content is considered as the contribution to a coalition, the vector $\mathbf{p} = (p_1, \ldots, p_N)$ can be defined as $p_i = \frac{1}{|M_i|} \left(\sum_{l \in M_i} p_{il}^P \right)$, where $M_i = \{l \,|\, D_{li} \in \mathbf{P}_i\}$, to represent the average popularity factor in the coalition. Alternatively, if a P2P network regards the upload link quality of

$^*\mathbf{d}$ is also called the disagreement point.[17]

peers as their contributions, the vector $\mathbf{p}$ can be defined as $p_i = L_i^U$, $i = 1, \ldots, N$. Therefore, the PBS for the bargaining problem $(\mathbf{S}, \mathbf{d})$ is uniquely determined as

$$\mathbf{X}^* = (X_1^*, \ldots, X_N^*) = F_{PBS}(\mathbf{S}, \mathbf{d})$$

on the set $\mathbf{B}$ given the vector $\mathbf{p}$. The corresponding value of the coalition $\mathbf{N} = \{1, \ldots, N\}$ is expressed as

$$v(\mathbf{N}) = \sum_{i=1}^{N} X_i^*. \tag{15}$$

Note that the value is also uniquely determined by PBS. Hence, given the vector $\mathbf{p}$, the unique utility pair selected by PBS from the bargaining set is optimal from the achievable utility perspective. Therefore, the PBS can be interpreted as a proportional division scheme for the each peer's marginal contribution to a coalition given the inter-peer utility comparison ratio.

Based on this interpretation of the PBS, an incoming peer that wants to join a coalition will choose the coalition that provides the largest utility after the division of the value given the vector $\mathbf{p}$ of the associated bargaining set. This provides a coalition selection algorithm for an incoming peer in a P2P network, and it is presented in Algorithm 1.

Algorithm 1 Coalition Selection Procedure

Require: Information about existing coalitions and peers for an incoming peer i in a P2P network from the central directory server.

1. Find set of coalitions $\mathbf{C}$ that include matched peers.
2. For each coalition $C \in \mathbf{C}$, find set of feasible coalitions $\mathbf{C}_F = \{C | v(C \cup \{i\}) > v(C) + v(\{i\})\}$.
3. For every $C \in \mathbf{C}_F$, calculate marginal contributions $\Delta v_i(C) = v(C \cup \{i\}) - v(C)$.
4. Choose the coalition $C^* \in \mathbf{C}_F$ that provides the largest division of marginal contribution: $C^* = \arg\max_{C \in \mathbf{C}_F} \left\{ \Delta v_i(C) \cdot p_i / \sum_{l=1}^{|\mathbf{p}|} p_l \right\}$.

4. SIMULATION RESULTS

In this section, we provide simulation results of the proposed framework for matching peers for multimedia transmission over P2P networks. We implement our P2P system similar to the PlanetLab platform,[11] which has been implemented developed using an instrumented version of the official BitTorrent implementation. We assume that each peer has their multimedia content that will be appropriately encoded (e.g., H.264/AVC encoder) and streamed using novel P2P technologies such as.[8,10] We assume that currently 1000 peers are registered with the central directory server.

4.1 Coalition Selection based on Marginal Contribution

In the proposed multimedia P2P network, since there can be several coalitions that fulfill their requirements, incoming peers need to select one of them to join. Since the division of marginal contribution based on the PBS becomes the achievable utility of peers in the coalition, peers choose the coalition that provides the largest division of marginal contribution. In this simulation, we focus on two representative coalitions ($C_1 = \{1, 2, 3\}$ and $C_2 = \{4, 5\}$) and investigate the effect of the coalition selection in terms of the achievable utility. As an illustrative example, we consider three incoming peers (I_i, $i = 1, 2, 3$). The attributes of the peers in the coalitions and the incoming peers are shown in Table 1, Table 2, and Table 3, respectively.

Note that the values of both coalitions are determined by the PBS with the vector $\mathbf{p} = (1/3, 1/3, 1/3)$ for C_1 and $\mathbf{p} = (1/2, 1/2)$ for C_2 as illustrative examples. As we discussed, this vector can be adaptively set based on the goal of the coalitions. The marginal contributions and the corresponding achieved utilities are determined by the PBS given a vector $\mathbf{p}$.

Simulation results are shown in Table 4 and Table 5 (MC=Marginal Contribution, AU=Achieved Utility, V=Coalition Value). In Table 4, both coalitions consider that the incoming peers' contributions are the same

	$\mathbf{P}_i$	$\mathbf{D}_i$	L_i^U [Kbps]	p_{ij}^D	c_i [dB/Kbps]	Utility
A_1	Foreman, Coastguard, Akiyo	Mobile	720	0.3	1.9×10^{-3}	19.36
A_2	Foreman, Coastguard	Stefan	580	0.2	2.1×10^{-3}	19.36
A_3	Foreman, Coastguard	Mobile	400	0.3	2.2×10^{-3}	19.36
Coalition Value						**58.08**

Table 1. Peer's Attributes in Coalition 1

	$\mathbf{P}_i$	$\mathbf{D}_i$	L_i^U [Kbps]	p_{ij}^D	c_i [dB/Kbps]	Utility
A_4	Foreman, Stefan	Coastguard	533	0.5	1.5×10^{-3}	20.20
A_5	Foreman, Stefan, Akiyo	Mobile	311	0.5	1.0×10^{-3}	20.20
Coalition Value						**40.40**

Table 2. Peer's Attributes in Coalition 2

	$\mathbf{P}_i$	$\mathbf{D}_i$	L_i^U [Kbps]	p_{ij}^D	c_i [dB/Kbps]
A_{I_1}	Mobile	Foreman	600	1	1.0×10^{-3}
A_{I_2}	Mobile	Akiyo	500	0.5	1.0×10^{-3}
A_{I_3}	Coastguard	Stefan	500	0.5	1.0×10^{-3}

Table 3. Incoming Peers' Attributes

	Coalition 1 (C_1)				Coalition 2 (C_2)				
	p	V	MC [dB]	AU [dB]	**p**	V	MC [dB]	AU [dB]	Benefit [dB]
I_1	[1/3, 1/3, 1/3]	82.41	24.33	**8.11**	[1/2, 1/2]	56.26	15.86	7.93	**0.18**
I_2	[1/2, 1/2]	77.84	19.76	**9.88**	[1/2, 1/2]	56.56	16.16	8.08	**1.80**
I_3	-	-	-	-	[1/2, 1/2]	58.70	18.30	**9.15**	**9.15**

Table 4. Marginal Contribution of Incoming Peers.

	Coalition 1 (C_1)				Coalition 2 (C_2)				
	p	V	MC [dB]	AU [dB]	**p**	V	MC [dB]	AU [dB]	Benefit [dB]
I_2	[1/2, 1/2]	77.84	19.76	**9.88**	[1/2, 1/2]	56.56	16.16	8.08	**1.80**
I_2	[1/4, 3/4]	69.04	10.96	2.74	[1/2, 1/2]	56.56	16.16	**8.08**	**5.34**

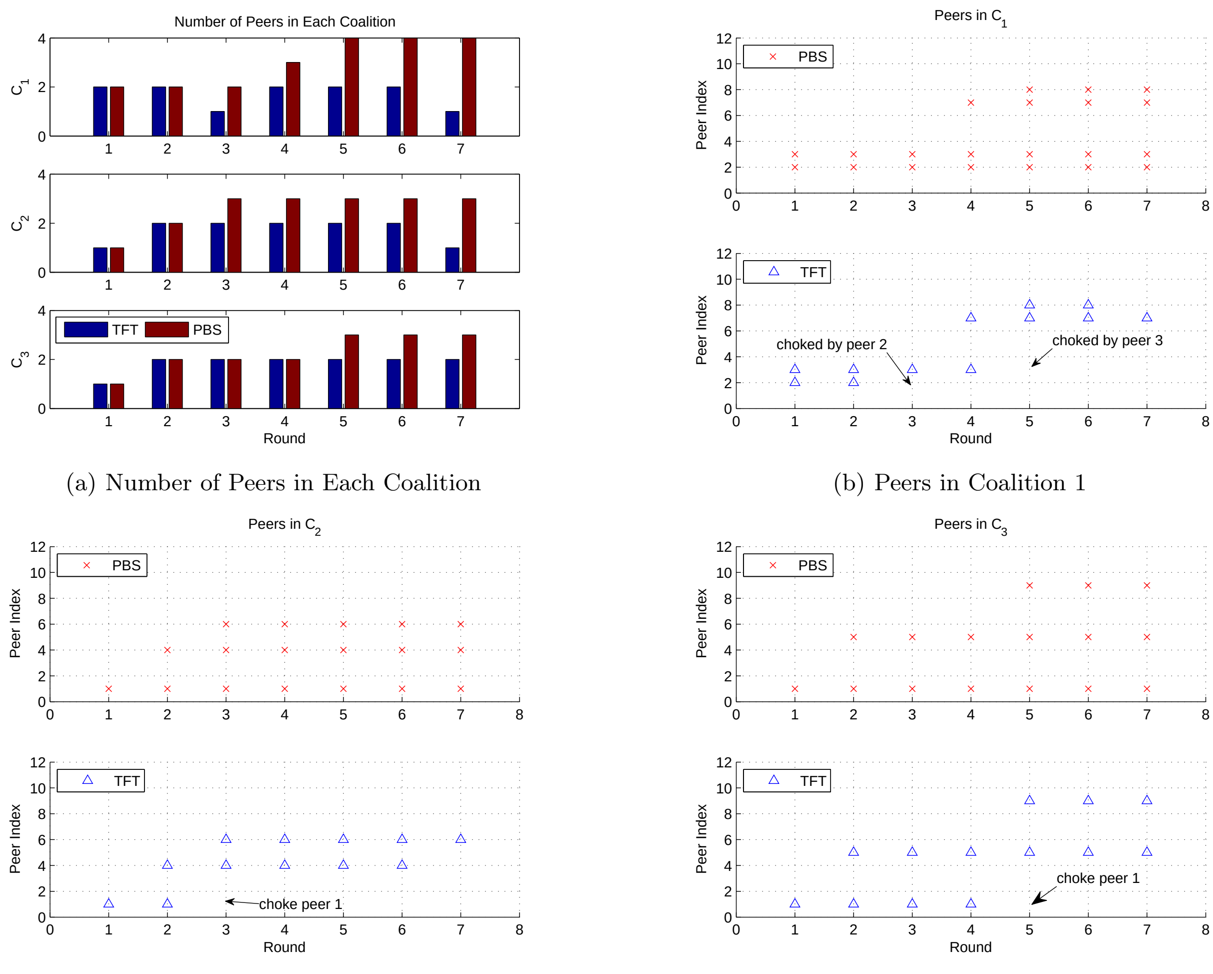
Table 5. Marginal Contribution of Incoming Peer 2.

to existing coalition peers (i.e., **p** has the same weight components). Based on the coalition selection algorithm in Algorithm 1, incoming peers gain benefits of 0.18dB, 1.80dB, and 9.15dB, respectively, by choosing the best coalition. Note that peer 3 achieves no utility in C_1 since it is a not matched peer to any of the two coalitions. The results can be easily extended to any number of peers.

The coalition selection algorithm becomes more important when the coalitions consider the incoming peers' contributions (i.e., **p** can have different weight components), which is determined by the goal of the coalition. Table 5 shows that incoming peer 2 can increase its utility benefit by choosing C_1 if $\mathbf{p} = (1/2, 1/2)$, while it benefits by choosing C_2 if $\mathbf{p} = (3/4, 1/4)$ is deployed. Hence, we conclude that the incoming peers should select the best coalition based on the largest division of marginal contribution and it can be implemented by the coalition selection algorithm.

4.2 Comparison with tit-for-tat Strategy

In this section, we compare the proposed coalition based upload bandwidth sharing strategy with a tit-for-tat strategy which is deployed in a P2P system such as BitTorrent.[11] To compare both strategies, we assume that there is no cost for providing upload bandwidth in coalition based bandwidth sharing strategy, as the tit-for-tat strategy does not consider it. Moreover, since the tit-for-tat strategy focuses only on the downloading rates from other peers, the utility in the proposed solution is defined as the downloading rates. The inter-peer utility comparison ratio vector is determined based on the download rates. We also assume that the maximum number of parallel uploads for a peer deploying the tit-for-tat strategy is two, as peers have the maximum number of parallel uploads in the leecher state.[11] The number of parallel uploads can be differently determined based on the peer's available upload bandwidth. In addition, peers do not guarantee to sustain their already established connections, as the tit-for-tat strategy does not guarantee them. In the following simulations, a peer creates its coalition with sequentially joining 11 peers, and bandwidth negotiation is performed in each round (i.e., when peers join or leave the coalition). The peer is downloading *Mobile* video sequence and the maximum upload bandwidth is 850 Kbps, which is the highest upload bandwidth among coalition peers. Note that all peers in the coalition provide their maximum upload bandwidth, which is assumed to be constant in this experiment, as no cost is imposed for providing their upload bandwidth.



(a) Number of Peers in Each Coalition

(b) Peers in Coalition 1

(c) Peers in Coalition 2

(d) Peers in Coalition 3

Figure 4. Peers in each coalition for different strategies (PBS and tit-for-tat (TFT)) over time (rounds).

Mobile	Average Download Rates	Average PSNR	$PSNR_{MAX}$	$PSNR_{min}$	$PSNR_{MAX} - PSNR_{min}$
PBS	723 Kbps	29.9 dB	32.6 dB	26.5 dB	6.1 dB
TFT	443 Kbps	26.6 dB	32.1 dB	21.6 dB	10.5 dB

Table 6. The Achieved Quality with Different Strategies

The simulation results are shown in Fig. 4, Fig. 5, and in Table 6. Fig. 4 shows the number and index of peers in selected coalitions (coalition 1, 2, and 3) over time (rounds). The corresponding download rates and the achieved quality of peer 1 are shown in Fig. 5 as an illustrative example. At the first 6 seconds (the first

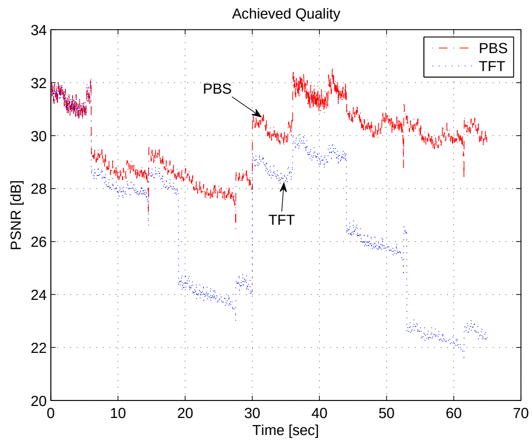


Figure 5. Download rates and the achieved quality for different strategies (PBS and tit-for-tat (TFT)).

round), the download rates (and hence the achieved quality) of peer 1 are the same for all the strategies (i.e., TFT and PBS) since the number of coalition peers are small (in this example, two peers (peer 2 and peer 3) are associated) and they provide their maximum upload bandwidth to peer 1. However, as more peers join the coalition and they create their own coalitions, download rates of peer 1 vary. Since the tit-for-tat strategy allows peers to maintain a fixed maximum number of parallel uploads with peers providing the highest upload rates, its download rates can be smaller than the proposed coalition based bandwidth sharing strategy (i.e., PBS). Moreover, due to the fixed number of parallel uploads in the tit-for-tat strategy, other peers can choke this peer, leading to significant loss of download rate and quality (e.g., the peer is choked by peer 2 and 3 at 20 second and at 50 second (round 3 and 5)). However, PBS does not abruptly deny to provide upload rates. Rather, it enables peers to scale the upload rates smoothly, leading to graceful changes of quality.

5. CONCLUSION

In this paper, we consider the problem of matching peers for multimedia P2P networks and identify strategies for fair upload bandwidth division among coalition peers. We propose a coalition selection algorithm based on the concept of marginal contribution, which enables peers to choose the best coalition, where peers can achieve the largest utility. Moreover, this algorithm can prevent free-riders from joining the coalitions, thereby not allowing peers to join a coalition unless they increase the coalition value. After peers make coalitions, the value of the coalition is fairly divided among participating peers based on the PBS, while exactly considering their contributions to the coalition. Simulation results show that the coalition selection algorithm plays an important role for incoming peers to achieve higher utilities and the PBS can manage each peer's upload bandwidth, providing rewards (in terms of utility) proportionally to their contributions to the coalition. Moreover, it is shown that the proposed coalition-based peer matching strategies can enhance the performance of existing P2P systems (e.g., BitTorrent) by efficiently dividing the available bandwidth based on the multimedia utility impact, thereby outperforming a simple tit-for-tat strategy.

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