

A P2P Traffic Management Model Based on an ISP Game

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Abstract—While P2P applications enrich the network application, they consume huge network bandwidth and have a great impact on ISP. As for current traffic optimization problem, maybe the most effective analysis tool is the game theory. This paper proposes an ISP-involved P2P network traffic management framework, builds a game model and its equilibrium solution, then from the perspective of evolution, performs convergence analysis on the equilibrium solution, based on this, generates a traffic management optimization algorithm, and discusses the fairness of the algorithm. Finally, the simulation experiments show that, the model can reach the purpose of optimizing traffic management.

Index Terms—Traffic Management, ISP, P2P, Game Theory

I. INTRODUCTION

P2P (Peer-to-Peer) is a distributed network, and a peer in the P2P network acts as the role of both a server and a client. While P2P applications enrich the network application, they consume huge network bandwidth and have a great impact on ISP (Internet Service Provider). In addition, the mismatch between the overlay networks and underlay networks leads to large redundant traffic, which strengthens the tension between P2P content providers and ISPs.

Many researchers try to solve this problem with such methods as cache management and traffic localization. GuoQiang Zhang etc. survey the P2P traffic optimization technologies from three aspects: P2P cache, traffic locality-awareness and data scheduling [1]. Literature [2] summarizes ISPs' P2P traffic management schemes: p2p blocking, p2p caching, Localization (peers), Localization (ISPs). In order to minimize the total amount of P2P traffic, Noriaki Kamiyama etc. present an optimum design for capacity and location of caches based on dynamic programming method, assuming that a transit ISP provides caches at transit links to access ISP networks [3]. Miyoshi etc. present a new method for P2P traffic localization, featuring the insertion of an additional delay into each P2P packet based on the geographic location of its destination [4]. Byungryeol Sim etc. have assessed the impacts of ALTO (Application-Layer Traffic Optimization Protocol) on P2P applications from the respects of network traffic optimization [5]. However, researches show that residential ISPs can actually lose money when localization is employed, and some of them will not see increased profitability until other ISPs

employ localization [6]. So, it's necessary to reduce traffic and increase ISP profit through cooperation between P2P and ISPs. Recently, some scholars study P2P traffic optimization problem from the cooperation between P2P and ISPs. Literature [7] has studied whether a cooperative caching scheme could help ISPs to decrease traffic costs caused by P2P applications. Literature [8] provides a ranking service that applies the ISP's own policies to the P2P peer selection flexibly. Through the peer selection policy, it can effectively control download traffic. Peng Yang etc. propose a rate allocation mechanism for achieving a balance between the cross-ISP P2P traffic and the P2P streaming performance [9].

As for current traffic optimization problem, maybe the most effective analysis tool is the game theory. From a theoretical perspective, it is feasible to achieve the purpose of traffic optimization if the ISP manages content through certain game strategy. There are many researchers apply game theory to P2P and ISP. Literature [10,11] describe a game theoretic framework for scalable video streaming over a P2P network. Literature [12] optimizes the non-cooperative P2P network from the game theory point of view. Literature [13] provides a new framework based on spatial evolutionary game theory for incentive mechanism to encourage cooperation among peers in P2P networks. Literature [14] presents a game theoretic framework to help the design of techniques encouraging the ISP cooperation in P2P streaming applications and decreasing unnecessary inter-ISP streaming traffic. Literature [15] formulates the interaction among ISPs and subscribers in a local market with two ISPs competing with each other as a two-stage game, and studies the influence of different traffic patterns on the Nash Equilibrium of the market. Literature [16] studies two games that model the adoption of ISP-driven locality promotion and of ISP-owned caches that intervene in the overlay.

In this paper, we apply game theory to P2P traffic optimization. The remaining of this paper is organized as follows: Section 2 proposes a P2P traffic management framework involved with ISPs. Section 3 establishes a game theory model and solves the Nash equilibrium, and analyzes convergence property of the Nash equilibrium from respect of evolution. On the basis of above, a P2P traffic optimization algorithm is presented, and its fairness is discussed. In section 4, the simulative result shows that the model can achieve the effect on traffic

optimization. Finally, section 5 concludes the work and points out future research directions.

II. BASIC HYPOTHETICAL FRAMEWORK

There are two hypotheses for the model.

(1) The P2P networks may possibly be of great differences between topologies of the underlying network and the carrying network, and the span of ISP domains may also be very great. Here, we assume that in this paper, the peer and ISP domains are relatively concentrated, without consideration of the marginal situation. Based on this hypothesis, some additional overhead and delay of resources during a request can be ignored. This is reasonable and critical for analysis of the core problem.

(2) Assume that, the resource request and transmission process of the peer node is controllable in a certain range. This helps to build and analyze the model conveniently when analyzing the activity process of a node.

When the peer node in this paper requires a resource, the required traffic request information is submitted to the P2P Resource Management System (RMS), according to related information of the task type and the ISP domain of the request, RMS divides the traffic request into sub-tasks corresponding to the ISP services, and then delivers them to the ISP for processing, finally in the part of ISP service provision, sets up links for peers and resources, in response to the request.

This is a two-level management model of mutual cooperation for P2P resource management system and ISP service provider. P2P RMS is the core part of the system, including not only Tracker but also the ability of dividing task requests into various sub-tasks, which can appear in the form of links or part resources. For example, when a node sends a resource request to the RMS, the Tracker finds that many places (ISP Cache or nodes in the domain) have the resources, and in order to select the optimal traffic path, the task is divided by RMS into multiple sub-requests to each ISP having the resources, and according to certain strategy to select and manage the path, the purpose of optimizing the traffic will be realized. According to the basic assumptions and analysis, the basic framework of the system can be obtained, as shown in Figure 1.

The framework of the system is divided into three layers. The bottom layer is a set of peers that are nodes with both the upload and download capabilities. The middle layer is a RMS, in which the system behaves as multiple sub-systems distributed in different places, with the functions of both Tracker and splitting the request. The top layer is a set of ISPs, which is direct interaction and choice with the RMS layer and the peer layer.

We assume that, in the whole controllable analysis network, there are n peer nodes, m RMS sub-systems and k ISP service processing parts. And assume that, i -th sub-RMS can divide peer traffic request information into t sub-tasks. Among them, the roles of each layer in this model should meet requirements as follows.

(1) Peer: provider and requester of the resource, which can generate a request for a resource, relatively independent of each other to generate the traffic task request. Assume that, average traffic request generated by the peer i is ω_i . The resource request generated by peer is divided into sub-tasks to ISP partly processing by P2P RMS system.

(2) RMS: the core of the system, which can receive the task request from the peer, the Tracker part is responsible for the inquiry of distribution of the resources, and then the request is divided into sub-tasks, sent to the corresponding ISP processing part. Assume that traffic request receiving by RMS i is γ_j , and requested traffic for RMS i sent to ISP j is ϕ_{ij} .

(3) ISP: the executor of requested task traffic, which is responsible for request routing and traffic management. The network topology that is actually owned by ISP can have the resource transmission path with optimal strategy choice optimization. Assume that, the average traffic for sub-tasks in the ISP j is Θ_j , the requested task

$$\text{is } \varphi_j = \sum_{i=1}^t \phi_{ij}.$$

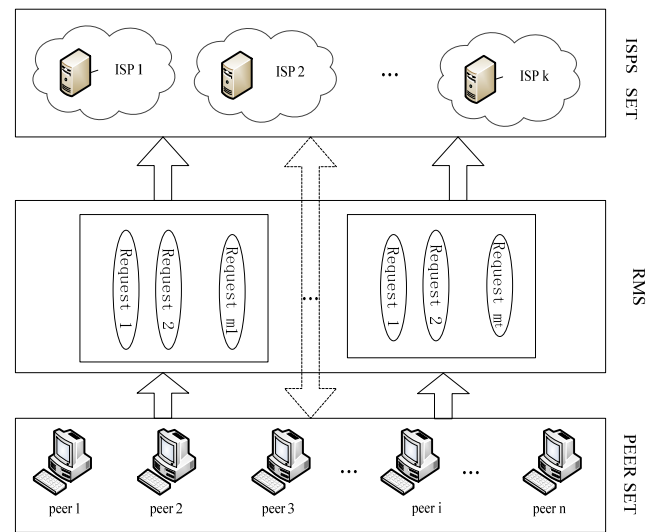


Figure 1. An ISP-involved P2P network traffic management framework

III. MODELING ON OPTIMAL NUMBERS OF CLUSTER HEADS

This section first analyzes and establishes a cooperative game model and its equilibrium solution, then from the perspective of evolution, performs convergence analysis on the equilibrium solution, finally generates a traffic management optimization algorithm based on the above, and discusses the fairness of the algorithm.

A. Basic Game Model

Assume that, a set of peer nodes in P2P network is set as N ($|N| = n$), and these nodes are owned by k ISPs. If

the set P_1, P_2, \dots, P_k meet requirements i, j , $1 \leq i, j \leq k$, $P_i \subseteq N$, $P_i \neq \emptyset$, $P_i \cap P_j = \emptyset$, $\bigcup_{i=1}^k P_i = N$, so that N nodes are assigned to k ISPs. P_i^k means that P_i^k i -th node belongs to the domain of P_k , which is $P_i^k \in P_k$. Here, it can be considered that P_i is an ISP set domain. In the network model as shown in Figure 1, the ISP processing sections by mutual cooperation, in accordance with the principle of optimal allocation, complete each task by RMS decomposition. When RMS decomposes the sub-tasks, each ISP provides a minimum of resources traffic load and fairness of task allocation. Based on this analysis, the ISP request processing section for the game model of the cooperation of the participants can be built.

The objective function of cooperative game is ISPs overall response to all traffic provided by peer requesting resources. Assume φ_j is the request traffic RMS sent to ISP j , the average traffic response of ISP j resource requested is

$$Q_j = 1/(\Theta_j - \varphi_j) \quad (1)$$

, and it also meet the following conditions.

$$\varphi_j \geq 0 \quad (2)$$

$$\varphi_j < \Theta_j \quad (3)$$

$$\sum_{j=1}^k \varphi_j = \sum_{i=1}^t \gamma_i \quad (4)$$

1 in the numerator of Formula (1) means that all traffic requests can be seen as a whole unit. Formula (2) means that the response of ISP j traffic request should be greater than 0, in other words, ISP j is in the active state. Formula (3) means that the response capability of ISP j should be less than the average traffic. Formula (4) means that all requests from the peer to the RSM and ISP ends should be equal.

B. Solving the Model

From the Nash equilibrium solution of the bargaining model, cooperative game defined by Formula (1) has a unique bargaining equilibrium solution, which is the optimal solution of

$$\max_{\varphi} T = \prod_{j=1}^k (\Theta_j - \varphi_j) \quad (5)$$

, and the constraint conditions are Formula (2) ~ (4). From the mathematical knowledge, the optimization problem of Formula (5) is equivalent to the optimal solution defined by

$$\max_{\varphi} T = \max_{\varphi} \prod_{j=1}^k \ln(\Theta_j - \varphi_j) \quad (6)$$

, in which Formula (6) does logarithm operations for each element, and the constraint conditions are still Formula (2) ~ (4). So Formula (1) is equivalent to Formula (6), with the solution as follows.

Taking into account $\partial Q/\partial \varphi_j \leq 0$ and $\partial^2 Q/\partial \varphi_j^2 \leq 0$, Q is a non-convex function, and the constraint conditions of Formula (2) ~ (4) is non-linear, so optimal solutions of Formula (6) satisfies the first-order Karush-Kuhn-Tucker (KKT) conditions. With Lagrange function, there is

$$L(\varphi_j, \alpha) = \prod_{j=1}^k \ln(\Theta_j - \varphi_j) + \alpha \left(\sum_{j=1}^p \varphi_j - \sum_{i=1}^q \gamma_i \right) \quad (7)$$

Assume $\partial Q/\partial \varphi_j = 0$, then

$$-1/(\Theta_j - \varphi_j) + \alpha = 0 \quad (8)$$

After further re-organization, there is

$$\varphi_j = \Theta_j - 1/\alpha \quad (9)$$

Put Formula (9) into the constraint equation (4), then

$$\sum_{j=1}^k \left(\Theta_j - \frac{1}{\alpha} \right) = \sum_{i=1}^t \gamma_i \quad (10)$$

Further, according to Formula (10), there is

$$\alpha = k / \left(\sum_{j=1}^k \Theta_j - \sum_{i=1}^t \gamma_i \right) \quad (11)$$

Finally, put Formula (11) into Formula (9), there is

$$\varphi_j^* = \Theta_j - \left(\sum_{j=1}^k \Theta_j - \sum_{i=1}^t \gamma_i \right) / k \quad (12)$$

According to the obtained result, the traffic equalization solution of ISP j in response to the request is φ_j^* . If only two ISPs are considered, $(\varphi_1^*, \varphi_2^*)$ is the optimal strategy solution. Similarly, the optimal strategy can be obtained by k ISPs.

C. Analysis of φ_j from the View of Evolution

In the process of solving the B part, after the requesting peer initiates the resource request, through a split and assignment, optimization is directly realized. But in fact, this is a process of dynamic convergence. From the evolutionary point of view, there are the fluctuation of iterations, repeated allocation and choice, gradually tending to a certain value, and eventually converging to the optimal strategy solution. By introducing parameter λ as evolution control parameter, the evolution iterative formula can be

$$\varphi_j^{s+1} = \begin{cases} \varphi_j^s (1 - \lambda) \\ \varphi_j^s + \lambda \Theta_j & \text{otherwise} \end{cases} \quad (13)$$

, in which $0 < \lambda < 1$, and assumes that the initial iterative value is from the beginning of φ_j^0 .

D. Algorithm Design

Through the analysis of B and C solutions, from Formula (12) and (14), when Θ_j satisfies

$$\Theta_j < \left(\sum_{j=1}^k \Theta_j - \sum_{i=1}^t \gamma \right) / k \quad (14)$$

, $\varphi_j < 0$. At this point, take $\varphi_j = 0$, the traffic has reached the maximum bandwidth, and can't handle the new resource request. Then, the best traffic management algorithm (BTMA) is as follows:

TABLE I.
THE BEST TRAFFIC MANAGEMENT ALGORITHM (BTMA)

for $j = 1$ to k
$\tau_j = \left(\sum_{j=1}^k \Theta_j - \sum_{i=1}^t \gamma \right)$
while φ_j not converge φ_j^*
Iterative φ_j^{s+1} until converge
end while
if $\tau_j > \varphi_j$ then
$\varphi_j = 0$
else
$\varphi_j = \Theta_j - \tau_j$
end if
end for

E. Algorithm Evaluation

Fairness is an important measurement index of the algorithm, mainly inspecting the differences of the response time of each participant with an algorithm. If the response time of each participant is smaller, it illustrates the fairness of the algorithm is better; otherwise, the fairness of the algorithm is poorer. The opportunity for all participants to obtain the response for the request should be same and fair.

In order to measure fairness of the algorithm, take the following Formula (15) as the fairness index.

$$F = \left(\sum_{j=1}^k Q_j \right)^2 / \left(k \times \sum_{j=1}^k Q_j^2 \right) \quad (15)$$

Put Formula (12) into Formula (1), the average traffic of response to ISP j resource request is

$$\Theta_j = k / \left(\sum_{j=1}^k \Theta_j - \sum_{i=1}^t \gamma_i \right) \quad (16)$$

Put Formula (16) into Formula (15) for the fairness index, $F = 1$ can be obtained. Here the fairness index

value 1 indicates that, in the cooperative game, each player is fair in the cost of traffic treatment.

IV. SIMULATION RESULTS AND ANALYSIS

This section is divided into two parts, which do simulation and verification of the model and algorithm in Section 2 and Section 3.

(1) Assume that, average traffic processing capabilities of ISPs are equal, possibly as 0.45Gb/s, then the traffic distribution management results is shown in Figure 2. As shown in Figure 2, the white histogram chart means the result without doing the optimal traffic management algorithm, and black columnar part is the results of ISP treatment by reasonable orientation and segmentation using the optimal traffic management algorithm.

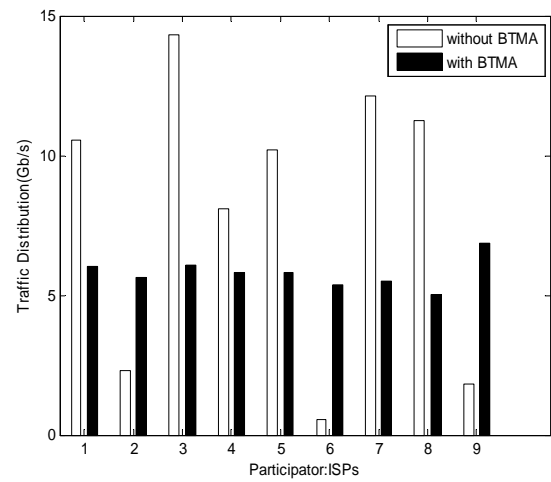


Figure 2. Traffic distribution management with same processing ability of ISPs

It can be seen that, traffic is random obviously without the BTMA algorithm, although the traffic management capabilities of ISPs are the same, but the resource request results reflect that, traffic of final treatment by each ISP is not the same, obviously in traffic management, such as ISP 1, 3, 4, 5, 7, 8 bear a larger load, and the traffic loads ISP 2, 6, 9 are very light, and the gap among traffic distribution is unfair to all the parties in the set of ISPs. The traffic distribution of BTMA algorithm has a small distribution fluctuation in the ISPs, which shows that in the process of cooperation, under the conditions of the same processing ability, traffic burden and its processing capacity of each ISP is roughly the same, with better fairness.

(2) Assume that there are 9 ISPs processing parts in the model, average processing capacity of each ISP part is shown in Table 2. Introduce the load coefficient ρ to measure load condition of the system, then the task request of RMS i is

$$\kappa_i = \rho \omega_i \sum_{j=1}^k \varphi_j \quad (17)$$

, in which ω_i is the average request traffic for peer i .

TABLE II.

AVERAGE TRAFFIC PROCESSING CAPACITY OF EACH ISP FOR PROCESSING RESOURCE REQUEST

ISP	Average traffic processing capacity (Gb/s)
1	0.12
2	0.49
3	0.96
4	0.34
5	0.59
6	0.22
7	0.75
8	0.26
9	0.50

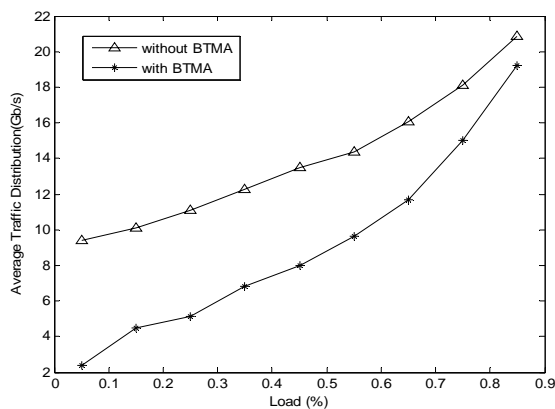


Figure 3. The distribution of average traffic cost of ISPs under different loads

For different load coefficients, the test results for average traffic handling of all ISP participants are shown in Figure 3. As seen from the Figure 3, when the load is small, the two have great differences, and when the load is more and more big, the gap between the two is reduced, but on the whole, the application of BTMA algorithm is better than non-usage, and obvious in the early time.

V. CONCLUSION

This paper proposes an ISP-involved P2P network traffic management framework based on the game theory, and analyzes and solves the model. Finally, the simulation results show that, this model can achieve the expectation of P2P network traffic optimization. This paper focuses on the relationship of cooperation between IPS and RMS. The next step of work is to improve the RMS, in order to realize engineering of traffic management.

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