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Cooperative Inter-ISP Traffic Control Scheme Based on Bargaining Game Approach

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ABSTRACT New applications in 5G networks are becoming very popular, and internet service providers (ISPs) may take the opportunity to provide various services to their clients. Today, one of the challenging problems facing ISPs is how the profitability can be increased while maintaining an excellent network performance. In this work, we seek to understand the fundamental issues on interactions among ISPs, and design a novel inter-ISP traffic control scheme to take full advantage of network resource sharing. Our approach explores the impact of ISP peering relationship and bandwidth allocation to maximize the total system revenue. Specifically, we identify the special properties of ISPs' interactions, and employ the concept of Yu bargaining solutions to address the ISP traffic control problem. This bargaining approach minimizes the Euclidean distance between the ISP's utopia payoff and the feasible solution set to provide a fair-efficient solution. The main novelty of our proposed scheme adaptively handling contradictory requirements while maximizing the network performance. To verify the benefits of our idea, we show the correctness of our scheme through carrying out extensive simulation experiments. Finally, several research challenges are discussed and open issues are also outlined.

INDEX TERMS ISP peering, inter-domain traffic engineering, cooperative game theory, Yu bargaining solution, weighted Yu bargaining solution.

I. INTRODUCTION

In recent years, the Internet has been evolving from a flatter structure to a hierarchical network platform due to the exponential increase in end user requests. This evolution of the Internet has resulted in more highly interconnected content providers in a multi-level structure. In the Internet infrastructure, Internet service provider (ISP) is an organization that provides services for accessing, using, or participating in the Internet. Generally, ISPs are classified into a 3-tier model that categorizes them based on the type of Internet services they provide. Tier-1 ISPs make up the Internet backbone and keep the global network inter-connected. By connecting tier-1 and tier-3 ISPs, tier-2 ISPs utilize a combination of paid transit via tier-1 ISPs and peering with other tier-2 ISPs to deliver Internet traffic to end customers through tier-3 ISPs. Tier-3 ISPs deliver Internet access to residential homes and businesses. Multiple ISPs in different tiers are tightly coupled with each other to operate the global Internet platform [1].

A key component of ISP operating mechanism is the ability to control how traffic enters or leaves any ISP domain. This is critical to ensuring that the ISP can offer good network system performance in the unbalanced traffic load situation. As the Internet is hierarchically structured, there are two types of relationships between ISPs for the ISP traffic control: transit and peering. Transit refers to the service of allowing network traffic to cross different tiers. In most cases, transit is paid for by the ISPs located in a lower tier to achieve access to the rest of the Internet. In a peering relationship, the traffic between the corresponding ISPs can be exchanged to achieve a mutual benefit. Nowadays, the impact of transit and peering is becoming increasingly significant. In a stable, efficient and predictable manner, new dynamic control protocols over inter-domain ISP traffic are necessary based on explicit coordination between ISPs [1], [2].

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Caching is a traditional technology for ISPs to save transit fees. Locally popular caching content inside the ISP network reduces the traffic volume crossing its network and transmission delay. Recently, with the fast development of ISP driven network, caching has attracted interest again. In addition, to overcome the size constraints of the local ISP cache, content-peering has been proposed as a promising policy between ISPs; this approach can help reduce the transit overhead. Especially, promoting ISPs of lower tiers to share caches has substantial benefits. However, this is very challenging in the current Internet state. A major limitation of content peering is that it is dominated by the peering links, which provide connections between ISPs. Therefore, to enable the inter-domain cache sharing between ISPs, efficient peering link management is necessary [1].

One of the main problems for link management issues is how to increase the profit while sustaining a better performance as the Internet grows. For ISPs in the multi-tier platform, they need to sell or purchase the transit and peering services. They set their prices based on the service provisioning and the amount of transferred traffic. The pricing mechanism for ISP driven services is currently based on access bandwidth and usage. However, with the growing diversity of applications, there is considerable interest in designing a multi-level ISP architecture that would allow ISPs to indicate the value they place on network service. Service-dependent pricing has been proposed as a method of traffic management that can efficiently allocate bandwidth among ISPs, which place different values on their requests. This mechanism ensures that ISPs have an incentive to control traffic congestion to best satisfy their requirements at the given price [3], [4].

The decisions for proper price and bandwidth allocation are not trivial. Note that individual ISPs want to maximize their own payoffs and reduce their operating costs. To satisfy this goal, a good pricing strategy is essential. In general, an adaptive pricing strategy can address the following issues: i) ISP profit maximization, ii) effective ISP bandwidth allocation, and iii) total network system capacity. However, each ISP's strategy may depend on strategies taken by other ISPs. Therefore, we need a strategic control paradigm to design our inter-ISP traffic management scheme. In this study, we follow a game-theoretic approach to answer this question. Based on the concept of cooperative game theory, we formulate the price decision and bandwidth allocation problems as a two-step interactive bargaining game model. At the first step, each ISP dynamically decides its service price. At the second step, the limited ISP bandwidth resource is adaptively distributed for transit and peering services. Based on the dynamic interactive process, two game steps work together in a coordinated manner toward an appropriate system performance.

A. TECHNICAL CONCEPTS

Generally, game theory is a theoretical framework for conceiving social situations among competing players. In some respects, game theory is the science of strategy, or at least the optimal decision-making of independent and competing actors in a strategic setting. Although game theory has a wide range of applications, including politics, economics, and business, psychology, evolutionary biology, and computer science, it is still a young and developing science. Despite there are many types of game models, cooperative games have recently become a hot research topic while receiving a generous concern. Originally, the earliest major contribution for cooperative games was made in 1950 by J. Nash. It is the unique bargaining solution to a two-person cooperative game based only on information about each player's preferences. However, one of the criticisms of Nash bargaining solution is precisely that it is not fair, in the sense that it ignores the players' ideal payoffs [5], [6].

For multi-objective optimization problems, P. L. Yu proposed a new bargaining solution, called Yu bargaining solution (*YBS*). As a symmetric or weighted version of the Euclidean compromise solution, it can minimize a measure of the distance between a feasible set and the utopia point of that set. Therefore, the *YBS* is closely related to solutions that have been proposed in the literature that studies bargaining with claims. Recently, the *YBS* was characterized to study main features such as efficiency and fairness. An interesting attribute of this characterization is that it is formally dual to the standard characterization on the Nash bargaining solution. If we believe that game players insist on some minimum payoff level, but are willing to cooperate fully with each other if a mutually acceptable way to share the surplus can be found, then the *YBS* is the most suitable solution [7].

B. MAIN CONTRIBUTIONS

According to the two-step bargaining game model, we can effectively handle the inter-ISP traffic control problem. In a cooperative and coordinated manner, each individual ISP makes decisions to reach a mutually acceptable agreement. Based on the currently different status, ISPs have different viewpoints for the service price and resource allocation strategy. By using the step-by-step interactive feedback process, the result of the price decision is the input back to the bandwidth distribution mechanism. The dynamics of our two-step bargaining process can cause cascade interactions of multiple ISPs to find the most profitable solution while resolving conflicting requirements. Therefore, the main novelty of our proposed scheme is its adaptability, flexibility and responsiveness to current ISP traffic conditions. In detail, the major contributions of this study are summarized as;

- This study investigates the ideas of cooperative game theory to design our inter-ISP traffic control scheme. By considering the conflicting views of ISPs, we formulate the interactions among different ISPs as a two-step cooperative game model.
- At the first-step game model, the service price of each individual ISP is dynamically decided according to the idea of *YBS*. At the second-step game model, each individual ISP distributes its limited bandwidth resource based on the basic idea of *Weighted YBS* (*WYBS*).

- Through the multi-level interactions among ISPs, we can get a reciprocal consensus generated by given the *YBS* and *WYBS*. The main characteristic of our proposed scheme lies in its responsiveness to the current traffic conditions to attain a globally desirable solution.
- We verify the correctness and the potential benefits of our proposed protocol with rigorous analysis and extensive experiments. According to the comparison with other existing state-of-the art protocols, we can confirm that our two-step cooperative game model can lead to a better system performance such as ISP payoff, system throughput and ISP traffic fairness.

C. ORGANIZATION

The rest of the paper is organized as follows. In Section II, we review the related work about the ISP traffic control issue. In Section III, we introduce the multi-level inter-ISP system infrastructure, and the fundamental concept of *YBS* and *WYBS*. And then, we formulate the price decision and bandwidth allocation problems as a novel two-step bargaining game model. To increase readability, the main steps of our proposed algorithm are given. In Section IV, we use simulation and experiment results to quantify the potential of our proposed protocol, and to provide insight into the characteristics of two-step game model. Finally, main findings of this study are summarized in Section V.

II. RELATED WORK

To address various traffic control problems in the inter-ISP platform, multiple literature papers have been published. This section presents a brief review of some related work. In [10], S. Borst et al develop light-weight cooperative cache management algorithms aimed at maximizing the traffic volume served from cache and minimizing the bandwidth cost. Especially, they focus on a cluster of distributed caches, and formulate the content placement problem as a linear program to get the globally optimal performance. Therefore, the main challenge in [10] is to actively manage the content placement to minimize the network traffic.

The paper [11] proposes an efficient collaborative caching mechanism based on the topology derived from a real-world system, with a particular focus on exploring the capacity of the existing system infrastructure. Based on heterogeneous request patterns at different locations of the system and asymmetric settings of cache capacities, the study in [11] designs the strategic content placement strategy and the corresponding request routing rules. To support new scenarios of massive content distribution, the practical distributed algorithm is achieved while exploring the existing network infrastructure.

Authors in [12] propose a contract theory-based incentive mechanism in which the network operator designs and offers an optimal contract to various types of several content providers. This is because in commercial caching systems, several content providers can be untruthful and not reveal accurate private information in order to mislead the network operator into charging them much lower prices or giving them more cache space. Based on the cache allocation, they consider the user association problem to maximize the social welfare, defined as the sum of the tradeoff of the data rates and the end-to-end delay of users. And then, they formulate the problem of user association as a many-to-many matching game with externalities, and propose a matching algorithm to achieve a two-sided exchange stable matching within a limited number of iterations [12].

The paper [13] considers the service provider level cooperation in caching in light of coalitional game. This paper explores the main questions of whether the cooperation always benefits and how the operational cost is reasonably shared among the service providers. The transferable-payoff coalitional game model is applied to the formulation. The service providers tend to form coalitions to reduce their operational cost. The characteristic function used in the coalitional game model is a linear program to minimize the network bandwidth expense. Solving the linear program also yields the optimal content placement and distribution strategies [13].

Despite the papers [10]–[13] provide very interesting ideas about the ISP traffic control problem, they strongly focus on the cooperative caching mechanism. Therefore, the important feature that distinguishes our work from the studies [10]–[13] is the control issues. We concentrate on the price decision and bandwidth allocation problems; not the cache management and replacement algorithms.

X. Shao *et al.* propose the *Cooperative Inter-Domain Sharing* (*CIDS*) scheme based on the inter-domain cache sharing to ISPs with different tiers [1]. To design the *CIDS* scheme, they study the inter-domain cache-sharing market with ISPs of different tiers, and analyze the ISPs' interactions. ISPs in different tiers have special properties, which make it difficult for ISPs to optimize traffic engineering and pricing decision. Based on the multi-tier ISPs infrastructure, they employ the Nash bargaining solution to jointly address the traffic engineering and pricing negotiation issues. This proposed bargaining mechanism is optimal in both technological and economic aspects. In addition, by considering the number of ISPs and the universal contents, they present a new decentralized algorithm to reach the design objective in a scalable way. Finally, they verify the correctness and the potential benefits to ISPs with rigorous analysis and extensive experiments [1].

The paper [8] proposes the *Traffic Scheduling and Revenue Distribution* (*TSRD*) scheme to investigate various traffic scheduling policies and conditions, which present different degrees of content-value preference and network neutrality. Under different traffic demand and network bandwidth, a new coalition game, called revenue sharing game, has been proposed with the goal of accurately modeling the cooperation decision of content ISPs. Using the notion of *Shapley value* from cooperative game theory, the *TSRD* scheme proves that the higher-value content scheduling approach can maximize the worth over all possible scheduling policies. When the network bandwidth exceeds traffic demand, the developed revenue sharing algorithm based on *Shapley value* leads ISPs to entirely cooperate, and provides the stability of grand coalition. It ensures useful implications on i) when and how multi-level ISP settlements help, and ii) how the Internet should be operated for stable peering and revenue balance among ISPs [8].

In paper [9], authors develop the *Resource Allocation and Revenue Maximization* (*RARM*) scheme to understand the fundamental issues on the interactions among ISPs at different tiers. Each individual ISP needs to perform proper resource allocation while maximizing its revenue. In order to maximize the total profit and attract more potential ISPs, a good pricing strategy is essential. To explore the impact of peering relationship and the revenue maximization, the *RARM* scheme is designed as a generalized model to characterize the behaviors of ISP, in which their economic interests are reflected. In this scheme, ISPs can utilize the available information to infer their optimal pricing strategies while achieving the revenue maximization. Extensive simulations are carried out to support that the *RARM* scheme can help ISPs to provide a fair and efficient bandwidth allocation to peers, and to avoid a resource monopolization of the market [9].

Although a lot of researches have exploited extensively the traffic control techniques to improve the inter-ISP system platform, none of the researches in the literature consider the two-step bargaining approach to handle the price decision and bandwidth allocation problems from an interactive perspective. Therefore, in our proposed scheme, a fair-efficient control solution has been fully utilized to get mutual advantages based on the different ISP status and control viewpoint.

III. THE PROPOSED SCHEME FOR INTER-ISP CONTROL ISSUES

In this section, we introduce the system model that characterizes the properties of the inter-ISP infrastructure. Then, we introduce the basic ideas of *YBS* and *WYBS* to design our two-step bargaining game model. Finally, the main step procedures of our proposed inter-ISP traffic control algorithm are delineated to help readers' comprehension.

A. INTER-ISP NETWORK SYSTEM INFRASTRUCTURE

We consider a regional network, which consists of tier-2 and tier-3 ISPs. They have local caches to cache popular content locally, and we do not consider the cache mechanism for the tier-1 ISPs. For the inter-ISP platform aspect, we assume that each ISP advertises information about the content in their local caches periodically. If a required content from end user is not cached locally, the tier-3 ISP would prefer obtaining the content from its neighbors' ISPs or its corresponding tier-2 ISP at a lower cost than from the tier-1 ISP. Let $\mathbb{I} = \mathfrak{P}_1 \cup \mathbb{N} \cup \mathbb{M}$ denote the set of ISPs; $\mathfrak{P}_1$ is the tier-1 ISP, and $\mathbb{N} = \{\mathcal{N}_1, \ldots, \mathcal{N}_n\}$ is the set of tier-2 ISPs, and $\mathbb{M} = \{\mathcal{M}_1, \ldots, \mathcal{M}_m\}$ is the set of tier-3 ISPs. Tier-2 and tier-3 ISPs are geographically dispersed, and $\boldsymbol{M}_{\mathcal{N}_i}$ is the set of tier-3 ISPs, which are connected to the $\mathcal{N}_i \in \mathbb{N}$ where $\mathcal{M}_{1\leq j\leq m} \in \boldsymbol{M}_{\mathcal{N}_i \subseteq \mathbb{N}} \subseteq \mathbb{M}$. Tier-3 ISPs in the $\boldsymbol{M}_{\mathcal{N}_i}$ are geographically close to each other, and interconnected together by signing up private peering agreements. Therefore, there is an opportunity to exchange information between themselves to effectively operate the inter-ISP traffic [1], [9]. The general multi-level inter-ISP system infrastructure is shown in Figure 1.

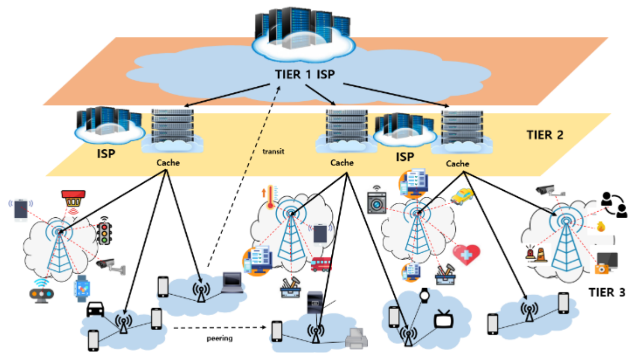


FIGURE 1. Multi-level inter-ISP system infrastructure.

We consider a discrete time model $T \in \{t_1, \ldots, t_c, t_{c+1}, \ldots\}$, where the length of a time slot matches the time-scale at which our control decisions are updated. In this study, a modeling situation for the ISPs' interaction process is formulated as the game ($\mathbb{G}$) ; $\mathbb{G}$ is subdivided into $\mathbb{G}^F_{t_c}$ and $\mathbb{G}^S_{t_c}$, and they are repeated sequentially in a slotted time structure. Based on the interactive feedback manner, our inter-ISP traffic control scheme is operated each time period during the step-by-step iteration. Formally, we define game entities for the multi-tier network system infrastructure, i.e,

$$\mathbb{G} = \left\{\mathbb{G}^F_{t_c}, \mathbb{G}^S_{t_c}\right\} = \left\{\{\mathbb{N}, \mathbb{M}\}, \mathfrak{M}_{BBU}, \left\{\mathbb{P}^{\mathcal{N}}, \mathbb{P}^{\mathcal{M}}\right\}, \right.$$
$$\left\{\mathcal{N}_i \in \mathbb{N} \mid \mathbb{A}^{\mathcal{N}_i}, \mathfrak{I}^{\mathcal{N}_i}, U^F_{\mathcal{N}_i}, U^{\mathcal{N}_i}_{SC}, U^S_{\mathcal{N}_i}, Q^{\mathcal{N}_i}\right\},$$
$$\left.\left\{\mathcal{M}_j \in \mathbb{M} \mid \mathbb{A}^{\mathcal{M}_j}, \mathfrak{I}^{\mathcal{M}_j}, U^F_{\mathcal{M}_j}, U^{\mathcal{M}_j}_{SC}, U^S_{\mathcal{M}_j}, Q^{\mathcal{M}_j}\right\}, T\right\}$$

of gameplay, and Table 1 lists the notations used in this paper.

- $\mathbb{G}$ is a two-step bargaining game consisting of $\mathbb{G}^F_{t_c}$ and $\mathbb{G}^S_{t_c}$ subgames; they are related in a coordination manner of mutual and reciprocal interdependency.
- $\mathbb{G}^F_{t_c}$ is the first-phase bargaining game at time t_c to decide the service price. In the $\mathbb{G}^F_{t_c}$, individual ISPs in $\mathbb{N}$ and $\mathbb{M}$ are game players, who are categorized as service providers or customers.
- $\mathbb{G}^S_{t_c}$ is the second-phase bargaining game at time t_c to allocate the bandwidth resource. In the $\mathbb{G}^S_{t_c}$, service request ISPs in $\mathbb{N}$ and $\mathbb{M}$ are game players.
- $\mathfrak{M}_{BBU}$ is a basic bandwidth unit to allocate the ISP traffic service.
- $\mathbb{P}^{\mathcal{N}} = \left\{\Theta^{\mathcal{N}}_{min} \ldots \Theta^{\mathcal{N}}_{h} \ldots \Theta^{\mathcal{N}}_{max}\right\}$ is a set of $\mathcal{N}$'s price strategies where Θ^{N}_{h} means the h^{th} price level to service one $\mathfrak{M}_{BBU}$. $\mathbb{P}^{\mathcal{M}} = \left\{\Theta^{\mathcal{M}}_{min} \ldots \Theta^{\mathcal{M}}_{h} \ldots \Theta^{\mathcal{M}}_{max}\right\}$ is a set of $\mathcal{M}$'s price strategies; $\mathbb{P}^{\mathcal{N}}$ and $\mathbb{P}^{\mathcal{M}}$ are the $\mathbb{G}^F_{t_c}$ game's strategies.
- $\mathbb{A}^{\mathcal{N}_i}$ is the bandwidth allocation vector of $\mathcal{N}_i \in \mathbb{N}$, and $\mathbb{A}^{\mathcal{M}_j}$ is the bandwidth allocation vector of $\mathcal{M}_j \in \mathbb{M}$; $\mathbb{A}^{\mathcal{N}_i}$ and $\mathbb{A}^{\mathcal{M}_j}$ are the $\mathbb{G}^S_{t_c}$ game's strategies.

TABLE 1. The notations for abbreviations, symbols and parameters.

Acronym	Explanations
ISP	internet service provider
YBS	Yu bargaining solution
WYBS	*Weighted YBS*
CIDS	*Cooperative Inter-Domain Sharing*
TSRD	*Traffic Scheduling and Revenue Distribution*
RARM	*Resource Allocation and Revenue Maximization*
PO	*Pareto Optimality*
TINV	*Translation Invariance*
IIA	*n-Independence of Irrelevant Alternatives*
SYM	*Symmetry*
CONT	*Continuity*
PLOSS	*Proportional Losses*
IF	*Individual Fairness*
Notations	**Explanations**
$\mathfrak{P}_1$	the tier-1 ISP
$\mathbb{N}$	the set of tier-2 ISPs where $\mathcal{N} \in \mathbb{N}$
$\mathbb{M}$	the set of tier-3 ISPs where $\mathcal{M} \in \mathbb{M}$
$\boldsymbol{M}_{\mathcal{N}}$	the set of tier-3 ISPs connected to the $\mathcal{N}$
$\mathbb{G}_t^F$	the first-phase bargaining game at time t
$\mathbb{G}_t^S$	the second-phase bargaining game at time t
n	the total number of tier-2 ISPs
m	the total number of tier-3 ISPs
$\Theta_{min}^{\mathcal{N}}$	the pre-defined $\mathcal{N}$'s minimum service price
$\Theta_{max}^{\mathcal{N}}$	the pre-defined $\mathcal{N}$'s maximum service price
$\Theta_{min}^{\mathcal{M}}$	the pre-defined $\mathcal{M}$'s minimum service price
$\Theta_{max}^{\mathcal{M}}$	the pre-defined $\mathcal{M}$'s maximum service price
$\mathfrak{M}_{BBU}$	a basic bandwidth unit for allocation
$\mathbb{P}^{\mathcal{N}}$	the set of $\mathcal{N}$'s price strategies
$\Theta_h^{\mathcal{N}}$	the h^{th} price level to service one $\mathfrak{M}_{BBU}$
$\mathbb{P}^{\mathcal{M}}$	the set of $\mathcal{M}$'s price strategies
$\mathbb{A}^{\mathcal{N}}, \mathbb{A}^{\mathcal{M}}$	the bandwidth allocation vectors of $\mathcal{N}$ and $\mathcal{M}$
$\mathcal{J}^{\mathcal{N}}, \mathcal{J}^{\mathcal{M}}$	the total link bandwidth amounts of $\mathcal{N}$ and $\mathcal{M}$
$U_{\mathcal{N}}^F, U_{\mathcal{M}}^F$	the utility functions of $\mathcal{N}$ and $\mathcal{M}$ in the $\mathbb{G}_t^F$
$U_{SC}^{\mathcal{N}}, U_{SC}^{\mathcal{M}}$	the utility functions of $\mathcal{N}$ and $\mathcal{M}$'s service customers
$U_{\mathcal{N}}^S, U_{\mathcal{M}}^S$	the utility functions of $\mathcal{N}$ and $\mathcal{M}$ in the $\mathbb{G}_t^S$
$\mathcal{Q}^{\mathcal{N}}, \mathcal{Q}^{\mathcal{M}}$	the local cache of $\mathcal{N}$ and $\mathcal{M}$
$\mathfrak{T}_{\mathcal{M}}$	the total traffic service amount of $\mathcal{M}$
σ, β, α	adjustment parameters for the $U_{\mathcal{M}}^F(\cdot)$
ζ, γ, μ	control parameters for the $U_{SC}^{\mathcal{M}}(\cdot)$
U_P^*	the utopia payoffs of service provider
U_C^*	the utopia payoffs of service customer
ω, ε, ξ	control factors for $U_{\mathcal{M}}^S(\cdot)$
η, φ	control factors for $U_{\mathcal{M}}^S(\cdot)$
$\mathbb{V}^{\mathcal{M}}$	ISPs, which request peer service to $\mathcal{M}$
$\mathcal{R}_I^{\mathcal{M}}$	the real-time traffic amount in $\mathcal{R}^{\mathcal{M}}$
$\mathcal{R}_{II}^{\mathcal{M}}$	the non real-time traffic amount in $\mathcal{R}^{\mathcal{M}}$
$\mathbb{U}_{\mathcal{M}}^*$	the utopia payoff of$\mathcal{M}$
χ	control parameters for *YBS* and *WYBS*
S	a set of feasible payoffs
d	a given disagreement outcome
ψ	decision factor for bargaining types

- $\mathfrak{I}^{\mathcal{N}_i}$ and $\mathfrak{I}^{\mathcal{M}_j}$ are the total link bandwidth amount of $\mathcal{N}_i$ and $\mathcal{M}_j$, respectively.
- At the $\mathbb{G}_{t_c}^F$, $U_{\mathcal{N}_i}^F$ and $U_{\mathcal{M}_j}^F$ are the utility functions of $\mathcal{N}_i$ and $\mathcal{M}_j$, respectively. The $U_{SC}^{\mathcal{N}_i}$ is the utility function of $\mathcal{N}_i$'s service customers, and $U_{SC}^{\mathcal{M}_j}$ is the utility function of $\mathcal{M}_j$'s service customers.
- At the $\mathbb{G}_{t_c}^S$, $U_{\mathcal{N}_i}^S$ is the utility function of $\mathcal{N}_i$, and $U_{\mathcal{M}_j}^S$ is the utility function of $\mathcal{M}_j$.
- $\mathcal{Q}^{\mathcal{N}_i}$ and $\mathcal{Q}^{\mathcal{M}_j}$ are the local cache of $\mathcal{N}_i$ and $\mathcal{M}_j$, respectively.
- $T = \{t_1, \ldots, t_c, t_{c+1}, \ldots\}$ denotes time, which is represented by a sequence of time steps.

B. THE BASIC CONCEPTS OF YBS AND WYBS

Typically, cooperative bargaining theory is an approach to solve social choice problems; it is in essence a payoff selection problem. In bargaining theory, solutions can be categorized into three classes. One approach is to find a solution that shares the gains among the game players as measured from the origin point, and captures a set of axioms that has a great deal of appeal. The other approach can be found in the bargaining with exogenously given claims on the social surplus. Based on these competing claims, game players reach a compromise and settle on some feasible payoff profile. A third alternative approach is that players must reach a compromise based on an endogenously determined but generally infeasible utopia point whose coordinates correspond to the maximum feasible payoffs attainable by the players [7].

As a solution in the third category bargaining solutions, the *YBS* has been introduced by P. Yu. In this study, we adapt the concept of *YBS* to design our inter-ISP traffic control scheme. To characterize the basic ideas of *YBS*, let $\mathbb{R}^n$ be the n-fold Cartesian product of real number set $\mathbb{R}$. An n-person bargaining problem consists of a pair (S, d) where $S \subset \mathbb{R}^n$ is a set of feasible payoffs. If game players fail to reach an agreement, they will use a given disagreement outcome $(d \in S)$ as the result. Formally, the *YBS* for all S is defined by using an endogenously determined aspiration point; it is given by [7].

$$YBS\,(S) = \arg\min_{x \in s} \left(\sum_{i \in \boldsymbol{N}} (u_i\,(S) - x_i)^{\psi} \right)^{\frac{1}{\psi}}, \quad \text{s.t.}, 1 \le \psi < \infty \tag{1}$$

where $\boldsymbol{N}$ is a finite set of game players, and ψ is a decision factor. Based on the value of ψ, we can define the concept *YBS*. If $\psi = 1$, the *YBS* becomes the utilitarian solution. If $\psi = 2$, it may minimize the Euclidean distance between the utopia point and the feasible set. If $\psi = \infty$, it corresponds to minimizing the Chebychev distance from the utopia point to the feasible set. Therefore, we can think that the *YBS* is a compromise bargaining solution. The idea of *YBS* can be generalized to a weighted version, i.e., *WYBS*, based on the asymmetric compromise; it is given by [7];

$$WYBS\,(S) \equiv \arg\min_{x \in s} \left(\sum_{j \in \mathbf{N}} \left(W_j \times \left[u_j\,(S) - x_j \right]^{\psi} \right) \right)^{\frac{1}{\psi}}, \quad \text{s.t.}, W \in \mathbb{R}_{++}^n, S \in \Sigma^{con} \tag{2}$$

The *WYBS* minimizes the distance between the utopia point and the feasible set where distance is defined in terms of a weighted metric on $\mathbb{R}^n$. Simply, the *WYBS* is the same as the *YBS* if W is a positive scalar multiple of e [7].

Generally, axioms are specified to characterize the bargaining solutions. Since each solution satisfies different axioms, they must have different properties. A collection of desirable axioms may be defined like as, *Pareto Optimality* (***PO***), *Translation Invariance* (***TINV***), *Independence of Irrelevant Alternatives* (***IIA***), *Symmetry* (***SYM***), *Continuity* (***CONT***), *Proportional Losses* (***PLOSS***), and *Individual Fairness* (***IF***). We now present standard axioms that will be used in the characterizations that follow:

- ***PO*:** no individual or preference criterion can be better off without making at least one individual or preference criterion worse off or without any loss thereof.
- ***TINV*:** it makes the utility invariant to translation. Invariance to translation means that if we translate the payoff, we can detect the class to which the payoff belongs.
- ***IIA*:** it is a condition that states that the relative likelihood of choosing from A from B won't change if a third choice is placed into the mix.
- ***SYM*** **:** it is a type of invariance; the property remains unchanged under a set of operations or transformations.
- ***CONT*** **:** it simply means that there are no jumps in game players' preferences.
- ***PLOSS*** **:** it is a general principle as a criterion of fairness.
- ***IF*** **:** it emphasizes on that similar individuals should be treated similarly.

Usually, approaches to bargaining problems fall into axiomatic categories. Therefore, the *YBS* and *WYBS* assume some desirable properties about the outcome, and identifies axioms that guarantee this outcome. The axioms involved in the characterization of *YBS* are ***PO***, ***TINV***, ***IIA***, ***IF***, ***CONT*** and ***PLOSS***. The *WYBS* may satisfy the axioms of ***PO***, ***TINV***, ***IIA***, ***SYM***, ***CONT*** and ***PLOSS*** [7].

C. THE TWO-STEP BARGAINING GAME MODEL FOR THE INTER-ISP SYSTEM

To decide the ISP's service price, each individual ISP designs the $\mathbb{G}_{t_c}^{F}$ as two-player game model; one player is service provider, i.e., each ISP, and the other player is all service customers, who are neighboring ISPs and represented as a single player. To ensure the fairness between service provider and customer, it is necessary that service provider and customer should be treated similarly in the $\mathbb{G}_{t_c}^{F}$. Therefore, the bargaining idea of *YBS*, which can guarantee the ***IF*** axiom, is suitable to implement the $\mathbb{G}_{t_c}^{F}$. As a service provider, the $\mathcal{M}_j$'s utility function with price strategy $\Theta_h^{\mathcal{M}} \in \mathbb{P}^{M}$, i.e., $U_{\mathcal{M}_j}^{F}\left(\Theta_h^{\mathcal{M}}\right)$, is defined with purely selfish and altruistic subjects. Formally, $U_{\mathcal{M}_j}^{F}\left(\Theta_h^{\mathcal{M}}\right)$ is given by;

$$U_{\mathcal{M}_j}^{F}\left(\Theta_h^{\mathcal{M}}\right) = \mathfrak{T}_{\mathcal{M}_j} \times \left(\left(\frac{\sigma}{exp\left(-\beta \times \Theta_h^{\mathcal{M}}\right)}\right) - \log\left(\Theta_h^{\mathcal{M}} + \alpha\right)\right) \quad (3)$$

where $\mathfrak{T}_{\mathcal{M}_j}$ is the total traffic service amount of $\mathcal{M}_j$. σ, β, α are adjustment parameters for the $U_{\mathcal{M}_j}^{F}\left(\Theta_h^{\mathcal{M}}\right)$. As a service customer, the utility function with price strategy $\Theta_h^{\mathcal{M}}$, i.e., $U_{SC}^{\mathcal{M}_j}\left(\Theta_h^{\mathcal{M}}\right)$, is formally derived as follows.

$$U_{SC}^{\mathcal{M}_j}\left(\Theta_h^{\mathcal{M}}\right) = \mathfrak{T}_{\mathcal{M}_j} \times \left(\frac{\zeta}{\left(\gamma + exp\left(-\Theta_h^{\mathcal{M}}\right)\right)} + \mu\right) \quad (4)$$

where ζ, γ and μ are control parameters for the $U_{SC}^{\mathcal{M}_j}\left(\Theta_h^{\mathcal{M}}\right)$. According to (3) and (4), the tier-2 ISP $\mathcal{N}_i$'s utility function, i.e., $U_{\mathcal{N}_i}^{F}(\cdot)$, and its customer's utility function, i.e., $U_{SC}^{\mathcal{N}_i}(\cdot)$ are defined as the same manner as the $U_{\mathcal{M}_j}^{F}(\cdot)$ and $U_{SC}^{\mathcal{M}_j}(\cdot)$, respectively. By using the solution concept of *YBS*, the $\mathcal{M}_j$'s price strategy at time t_c, i.e., $\Theta_{min\leq k\leq max}^{\mathcal{M}_j}(t_c) \in \mathbb{P}^{\mathcal{M}}$, is decided as follows;

$$\begin{aligned} YBS &= \arg \min_{\Theta_{min\leq k\leq max}^{\mathcal{M}_j}(t_c)} \left(\sum_{g\in\{P,C\}} \left(U_g^{*} - \mathbb{I}_g\left(\Theta_k^{\mathcal{M}_j}(t_c)\right)\right)^{\chi}\right)^{\frac{1}{\chi}} \\ &\text{s.t.}, \mathbb{I}_P\left(\Theta_k^{\mathcal{M}_j}(t_c)\right) = U_{\mathcal{M}_j}\left(\Theta_h^{\mathcal{M}}\right) \text{ and } \mathbb{I}_C\left(\Theta_k^{\mathcal{M}_j}(t_c)\right) \\ &= U_{SC}^{\mathcal{M}_j}\left(\Theta_h^{\mathcal{M}}\right) \end{aligned} \quad (5)$$

where U_P^{*} and U_C^{*} are the utopia payoffs of service provider and service customer, respectively. According to (5), the service price for each individual ISPs in the tier-3 area is decided, and this information is announced to its neighboring ISPs. The service price for ISPs in the tier-2 area is also decided as the same manner as the tier-3 ISP.

In the second-step game $\left(\mathbb{G}_{t_c}^{S}\right)$, service request ISPs are symmetric game players, and the limited bandwidth resource is dynamically allocated to maximize the system performance. When the $\mathcal{M}_j$ selects its price strategy $\Theta_k^{\mathcal{M}_j}$ at time t_c, the $\mathcal{M}_l$'s utility function for the peering service, i.e., $U_{\mathcal{M}_l}^{S}\left(\Theta_k^{\mathcal{M}_j}(t_c)\right)$, is formally defined as follows;

$$\begin{aligned} &U_{\mathcal{M}_l}^{S}\left(\mathcal{R}^{\mathcal{M}_l}, \Theta_k^{\mathcal{M}_j}(t_c), \mathfrak{R}_{\mathcal{M}_j}\right) \\ &= \left(Z_{\mathcal{M}_l}\left(\mathcal{R}_I^{\mathcal{M}_l}, \mathfrak{R}_{\mathcal{M}_j}\right) + H_{\mathcal{M}_l}\left(\mathcal{R}_{II}^{\mathcal{M}_l}, \mathfrak{R}_{M_j}\right)\right) \\ &\text{s.t.}, \begin{cases} Z_{\mathcal{M}_l}\left(\mathcal{R}^{\mathcal{M}_l}, \mathfrak{R}_{\mathcal{M}_j}\right) = \\ \frac{\mathcal{R}_I^{\mathcal{M}_l}}{\Theta_k^{\mathcal{M}_l}(t_c)} \times \left(\left(\xi + \exp\left(-\omega \times \left(\frac{\mathcal{R}_I^{\mathcal{M}_l}}{\mathfrak{R}_{\mathcal{M}_j}}\right)\right)\right)^{-1} - \varepsilon\right) \\ H_{\mathcal{M}_l}\left(\mathcal{R}^{\mathcal{M}_l}, \mathfrak{R}_{\mathcal{M}_j}\right) = \\ \frac{\mathcal{R}_{II}^{\mathcal{M}_l}}{\Theta_k^{\mathcal{M}_j}(t_c)} \times \log\left(\mathcal{R}_{II}^{\mathcal{M}_l} \big/ \mathfrak{R}_{\mathcal{M}_j} + \eta\right)^{\varphi} \\ \mathcal{M}_l \in \mathbb{V}^{\mathcal{M}_j}, \mathcal{R}^{\mathcal{M}_l} = \\ \mathcal{R}_I^{\mathcal{M}_l} + \mathcal{R}_{II}^{M_l} \text{ and } \mathfrak{R}_{\mathcal{M}_j} = \sum_{\mathcal{M}_d \in \mathbb{V}^{\mathcal{M}_j}} \mathcal{R}^{\mathcal{M}_d} \end{cases} \end{aligned} \quad (6)$$

where ω, ε and ξ are control factors for the $Z_{\mathcal{M}}(\cdot)$, and η, φ are control factors for the $H_{\mathcal{M}}(\cdot)$. $\mathbb{V}^{\mathcal{M}_j}$ is the set of ISPs, which request peer service to the $\mathcal{M}_j$. $\mathcal{R}_I^{\mathcal{M}_l}$ and $\mathcal{R}_{II}^{\mathcal{M}_l}$ are the real-time traffic amount and non real-time traffic amount in the $\mathcal{R}^{\mathcal{M}_l}$, respectively. Usually, real-time traffic has higher priority than non real-time traffic during network operations based on different tolerance characteristics.

In this study, ISPs are assumed to work together in a cooperative manner, and they negotiate with each other to fairly share the overloaded communication link. From the viewpoint of fairness, payoff should not discriminate between the identities of the players, but only depend on utility functions. Therefore, we should guarantee that if the players' utilities are exactly the same, they should get symmetric payoffs. Due to this reason, the ***SYM*** axiom is necessary in the $\mathbb{G}^S_{t_c}$, and we choose the concept of *WYBS* to solve the bandwidth allocation problem. By using the solution concept of *WYBS*, the $\mathcal{M}_j$'s bandwidth allocation strategy at time t_c, i.e., $\mathbb{A}^{\mathcal{M}_j} = [\ldots, \mathcal{R}^{\mathcal{M}_l}, \ldots]$, is decided as follows;

$$WYBS = \arg \min_{\mathbb{A}j=[\ldots,\mathcal{R}^{\mathcal{M}}l,\ldots]} \times \left(\sum_{\mathcal{M}_l \in \mathbb{V}^{\mathcal{M}_j}} \left(\mathcal{S}_{\mathcal{M}_l} \times \left[\mathbb{U}^*_{\mathcal{M}_l} - I^S_{\mathcal{M}_l}\left(\mathbb{A}^{\mathcal{M}_j}\right)\right]\right)^{\chi} \right)^{\frac{1}{\chi}}$$

$$\text{s.t.,} \begin{cases} I^S_{\mathcal{M}_l}\left(\mathbb{A}^{\mathcal{M}_j}\right) = U^S_{\mathcal{M}_l}\left(\mathcal{R}^{\mathcal{M}_l}, \Theta^{\mathcal{M}_j}_k(t_c), \mathfrak{R}_{\mathcal{M}_j}\right) \\ \mathcal{S}_{\mathcal{M}_l} = \mathcal{R}^{\mathcal{M}_l}_I \Big/ \sum_{\mathcal{M}_e \in \mathbb{V}^{\mathcal{M}_j}} \mathcal{R}^{\mathcal{M}_e}_I \text{ and} \\ \mathfrak{R}_{\mathcal{M}_j} = \sum_{\mathcal{M}_l \in \mathbb{V}^{\mathcal{M}_j}} \mathcal{R}^{\mathcal{M}_l} \leq I^{\mathcal{M}_j} \end{cases} \quad (7)$$

where $\mathbb{U}^*_{\mathcal{M}_l}$ is the utopia payoff of $\mathcal{M}_l$. The value of $\mathcal{R}^{\mathcal{M}_l}$ in $\mathbb{V}^{\mathcal{M}_j}$ is adaptively adjusted according to (7), and the bandwidth resource of $\mathcal{M}_j$ is distributed to the $\mathcal{M}_l \in \mathbb{V}^{\mathcal{M}_j}$. By using (6), the tier-2 ISP $\mathcal{N}_i$'s utility function, i.e., $U^S_{\mathcal{N}_i}(\cdot)$ is defined as the same manner as the $U^S_{\mathcal{M}_l}(\cdot)$, and the bandwidth resource of $\mathcal{N}_i$ is also distributed based on the same idea of the equation (7).

D. MAIN STEPS OF PROPOSED TWO-PHASE BARGAINING SCHEME

To provide opportunities to adaptively operate the inter-ISP system platform, we incorporate the role of two-step bargaining game model into our traffic control scheme. First, we wisely regulate the service price at each local ISP while integrating current local traffic condition; the dynamically decided price can balance the traffic flow to avoid traffic congestions. Second, the limited ISP link bandwidth resource is adaptively distributed for its transit and peering services. It enables ISPs to maximize their revenues. Based on our two-step bargaining approach, we implement our inter-ISP traffic control algorithm while facilitating the cooperative work of ISPs to get a fair-efficient solution, which can offer many advantages under widely different and diversified traffic situations. The main steps of the proposed scheme can be described as follows, and they are described by the following flowchart:

TABLE 2. System parameters used in the simulation experiments.

Parameter	Value	Description
n	10	the total number of tier-2 ISPs ($\mathcal{N}$)
m	50	the total number of tier-3 ISPs ($\mathcal{M}$)
$\Theta^{\mathcal{N}}_{min}, \Theta^{\mathcal{N}}_{max}$	0.2 , 1	the pre-defined minimum and maximum $\mathcal{N}$'s service prices
$\Theta^{\mathcal{M}}_{min}, \Theta^{\mathcal{M}}_{max}$	0.15 , 0.9	the pre-defined minimum and maximum $\mathcal{M}$'s service prices
σ, β, α	1, 1, 1	adjustment parameters for the $U^F_{\mathcal{M}}(\cdot)$
ζ, γ, μ	1.5, 1, 0.5	control parameters for the $U^{\mathcal{M}}_{SC}(\cdot)$
ω, ε, ξ	3, 0.5, 1	control factors for the $Z_{\mathcal{M}}(\cdot)$ in the $U^S_{\mathcal{M}}(\cdot)$
η, φ	1, 3	control factors for the $H_{\mathcal{M}}(\cdot)$ in the $U^S_{\mathcal{M}}(\cdot)$
χ	3	control parameters for *YBS* and *WYBS*
$\mathfrak{M}_{BBU}$	1 Gbps	the size of basic bandwidth unit

Traffic Type	Application	Bandwidth Requirement	Connection duration
I	1	96 MBPS	120 *ts*
	2	32 MBPS	150 *ts*
	3	64 MBPS	90 *ts*
II	4	128 MBPS	180 *ts*
	5	512 MBPS	60 *ts*
	6	256 MBPS	120 *ts*

Step 1: For our simulation model, the values of system parameters and control factors can be discovered in Table 2, and the simulation scenario is given in Section IV.

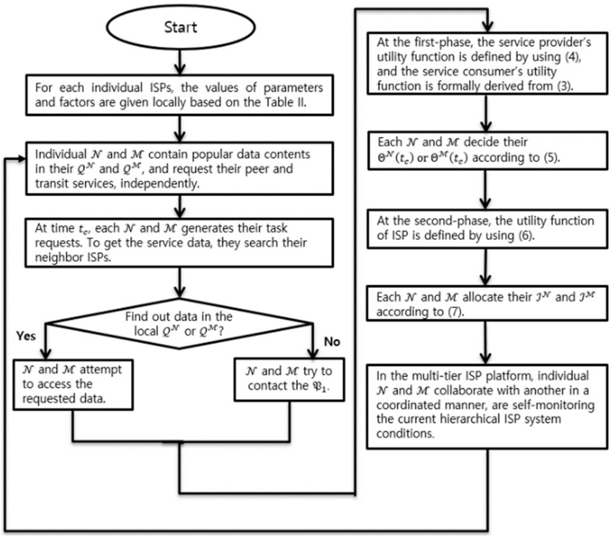
Step 2: In each discrete time period in T, individual $\mathcal{N} \in \mathbb{N}$ and $\mathcal{M} \in \mathbb{M}$ contain popular data contents in their $\mathcal{Q}^{\mathcal{N}}$ and $\mathcal{Q}^{\mathcal{M}}$, and request their peer and transit services, independently.

Step 3: Each $\mathcal{N}$ and $\mathcal{M}$ generates their task requests. To get the service data, they search their neighbor ISPs. If they find out their requested data in the local $\mathcal{Q}^{\mathcal{N}}$ or $\mathcal{Q}^{\mathcal{M}}$, they attempt to access them. Otherwise, they try to contact the $\mathfrak{P}_1$.

Step 4: At the first-phase, each $\mathcal{N}$ and $\mathcal{M}$ decide their service price, i.e., $\Theta^{\mathcal{N}}$ and $\Theta^{\mathcal{M}}$, based on the concept of *YBS*. The service provider's utility function is defined by using (4), and the service consumer's utility function is formally derived from (3).

Step 5: According to (5), the ISPs' price strategies at time t_c $\left(\Theta^{\mathcal{N}}(t_c) \text{ or } \Theta^{\mathcal{M}}(t_c)\right)$ are dynamically decided by considering the interactions ISPs.

Step 6: At the second-phase, individual $\mathcal{N}$ and $\mathcal{M}$ allocate their limited link bandwidth resource, i.e., $\mathcal{I}^{\mathcal{N}}$ and $\mathcal{I}^{\mathcal{M}}$, based on the concept of *WYBS*. As a game player, the utility function of ISP is defined by using (6).



FLOWCHART 1. Flowchart of the proposed algorithm

Step 7: According to (7), the ISPs' link bandwidth resources at time t_c are dynamically decided, like as $\mathbb{A}^M$ or $\mathbb{A}^N$, by ensuring the efficiency and fairness.

Step 8: In the multi-tier ISP platform, $\mathcal{N}$ and $\mathcal{M}$ collaborate with another in a coordinated manner to strike the appropriate performance balance while adaptively manipulating the current network traffic situations.

Step 9: Constantly, individual $\mathcal{N}$ and $\mathcal{M}$ are self-monitoring the current hierarchical ISP system conditions, and proceed to Step 2 for the next two-phase bargaining process.

IV. PERFORMANCE EVALUATION

In this section, we use numerical experiments to study the properties of the proposed method and the potential benefits for the multi-tier ISP platform. To validate our approach, we use computer simulations to compare the system performance with existing three protocols; the *CIDS*, *TSRD* and *RARM* schemes [1], [8], [9]. First, we describe the experimental settings and simulation scenario, and then, present the numerical analysis. The assumptions of our simulation environments are as follows:

- The simulated multi-tier ISP platform consists of one tier-1 ISP, 10 tier-2 ISPs, and 50 tier-3 ISPs where $|\mathbb{N}| = 10$ and $|\mathbb{M}| = 50$.
- Multiple ISPs are geographically dispersed over the global area, and one tier-2 ISP clusters five corresponding tier-3 ISPs in its covering area.
- Within the tier-2 ISP controlling cluster, all ISPs are connected each other to share their cache contents. If the requested data cannot be locally accessed within the cluster, it is necessary to contact the upper tier ISP while minimizing the access cost.
- In each ISP, the generation process for data access tasks is Poisson with rate Λ (services/t), and the range of offered tasks was varied from 0 to 3.0.
- The sizes of $\mathcal{I}^{\mathcal{N}}$ and $\mathcal{I}^{\mathcal{M}}$ are 500 Gbps and 150 Gbps, respectively.

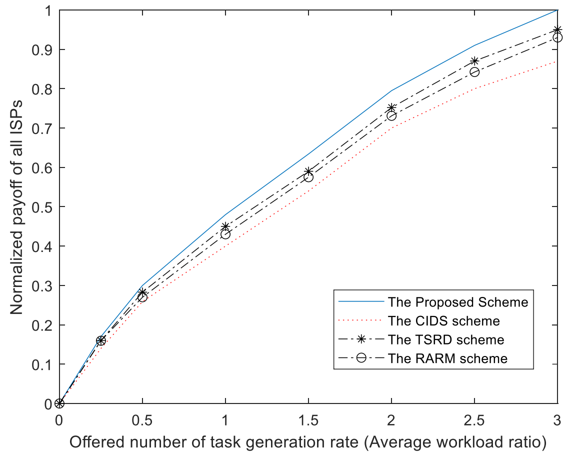


FIGURE 2. Normalized average payoff of all ISPs.

- The sizes of $\mathcal{Q}^{\mathcal{N}}$ and $\mathcal{Q}^{\mathcal{M}}$ are 30 GB and 10 GB, and the contents of them are dynamically decided according to the access popularity. Simply, we assume that newly generated tasks can be matched to a specific cache in a probability $\mathcal{P}_c = 0.1$.
- Six different kinds of data access tasks are assumed based on operation duration and communication requirement; they are assumed as the ISP's workload.
- The $\mathcal{N}$'s price strategy set $\mathbb{P}^{\mathcal{N}} = \{\Theta^{\mathcal{N}}_{min=1} \ldots \Theta^{\mathcal{N}}_{max=5}\}$ is defined as $\Theta_1^N = 0.2$, $\Theta_2^{\mathcal{N}} = 0.4$, $\Theta_3^{\mathcal{N}} = 0.6$, $\Theta_4^{\mathcal{N}} = 0.8$, and $\Theta_5^{\mathcal{N}} = 1$. The $\mathcal{M}$'s price strategy set $\mathbb{P}^{\mathcal{M}} = \{\Theta^{M}_{min=1} \ldots \Theta^{\mathcal{M}}_{max=5}\}$ is defined as $\Theta_1^{\mathcal{M}} = 0.15$, $\Theta_2^M = 0.3$, $\Theta_3^{\mathcal{M}} = 0.5$, $\Theta_4^{\mathcal{M}} = 0.7$, and $\Theta_5^{\mathcal{M}} = 0.9$.
- To reduce computation complexity, the amount of bandwidth allocation is specified in terms of basic bandwidth unit ($\mathfrak{M}_{BBU}$), where one $\mathfrak{M}_{BBU}$ is the minimum amount (e.g., 1 Gbps in our system) of computation process.
- System performance measures obtained on the basis of 100 simulation runs are plotted as a function of the offered task request load.
- Performance measures obtained are ISP payoff, system throughput and ISP traffic fairness in the multi-tier ISP platform.

Fig.2 shows the normalized average payoff of all ISPs as a function of the task generation increase. This result indicates that our proposed scheme can improve the ISPs' payoff than other existing state-of-the art protocols. As mentioned above, the proposed scheme explores the interaction of multi-tier ISPs, and algorithmically leverages selfish network agents to work together for their profits. It can lead to a higher ISP's payoff while effectively adapting the current traffic conditions in the hierarchical Internet infrastructure. Therefore, we confirm that the advantage of our proposed scheme can far outweigh the merits of *CIDS*, *TSRD* and *RARM* schemes under different traffic load situations.

Fig.3 provides the throughput comparison of multi-tier ISP system platform. Since the system throughput is estimated as the successfully completed traffic services, the simulation results are similar to those in Fig.2. As expected, we observe

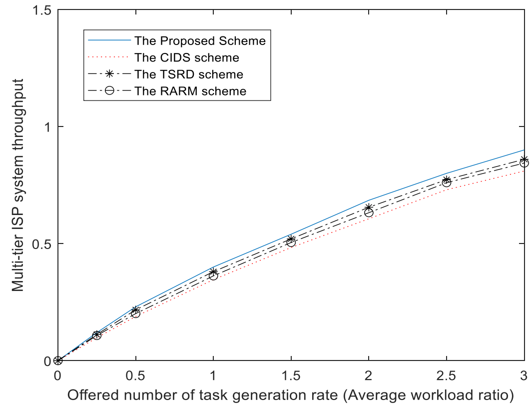


FIGURE 3. ISP traffic fairness.

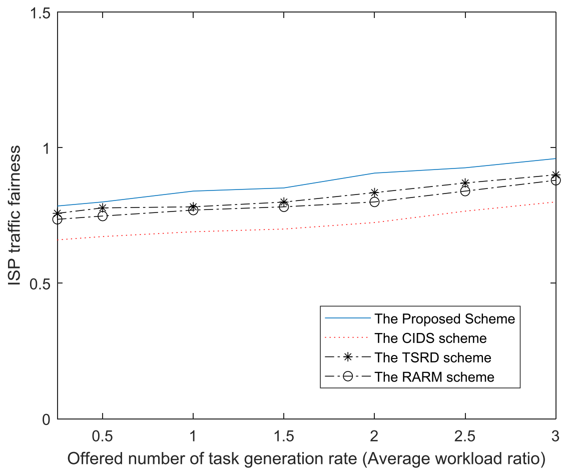


FIGURE 4. Multi-tier ISP system throughput.

that our two-phase bargaining approach has a comparatively better system throughput under light to heavy task load distributions. The major observation here is that our bargaining approach can efficiently share the limited system resource to operate network services. As a consequence of iterative two-phase bargaining process, control decisions are mutually dependent in an interaction relationship, and dynamically made during the step-by-step operation. This decision mechanism can transfer the computational burden from a central system to each tier's ISPs in a distributed online fashion. Therefore, it is suitable approach for the real world multi-tier ISP system in the point view of practical operations.

In order to effectively operate the complex and complicated Internet infrastructure, the fairness issue for individual ISPs is very important. Usually, the major challenge to develop new bargaining solutions is to provide the most proper combination of the efficiency and fairness. Our two-step bargaining approach can effectively compromise the contrasting viewpoints of different ISPs, and provides the most proper resource sharing protocol. Therefore, under diversified traffic condition changes, we can maintain the better fairness index than other existing *CIDS*, *TSRD* and *RARM* schemes. From the simulation results in Fig.2-Fig.4, it is evident that, in general, our two-step bargaining game model is a promising approach to meet the demands of multi-tier ISP system as compared with existing traffic control protocols.

V. SUMMARY AND CONCLUSIONS

In this paper, we investigate the interplay among different ISPs, and develop a detailed methodology to solve the inter-ISP traffic control problem. Based on the ideas of *YBS* and *WYBS*, we devise a novel two-phase bargaining game model to manage fair-efficiently the hierarchical Internet system resources. At the first phase, the service price of each ISP is dynamically decided according to the *YBS*. Based on the feedback mechanism, the price decision of ISP might affect the behavior of other IPSs. At the second phase, the limited link bandwidth of each ISP is adaptively distributed by using the *WYBS* to control intra and inter-domain ISP traffic flows. In particular, ISPs attempt to control traffic routing in their networks in order to optimize the usage of their network resources. Finally, we use extensive simulation experiments to evaluate the performance of our proposed approach, and show that our two-step bargaining model can obtain a better system performance such as ISP payoff, system throughput and ISP traffic fairness as compared with the existing *CIDS*, *TSRD* and *RARM* schemes. In the future, we would like to consider the ISP cooperation for a reasonably stable allocation of cache resources, and we will develop a new detailed methodology for evaluating the profitability of ISPs.

COMPETING OF INTERESTS

The author declares that there are no competing interests regarding the publication of this paper.

AUTHOR' CONTRIBUTION

The author is a sole author of this work and ES (i.e., participated in the design of the study and performed the statistical analysis).

AVAILABILITY OF DATA AND MATERIAL

Please contact the corresponding author at *swkim01@sogang.ac.kr*.

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