

An Equilibrium Policy for Providing End-to-end Service Level Agreements in Interdomain Network

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Abstract—In next generation networks, technological advancements lead a trend towards offering guaranteed services. ISPs are eager to support subscribers' requirements by offering SLAs across domains. This paper considers the interaction between ISPs under deregulatory environment. In order to capture a freedom of the policy selection, path-classification scheme is proposed to group paths into a few choices which ISPs can freely select. By means of Nash equilibrium, the equilibrium policy has been found with searching algorithm by applying the modified MSA. We investigate the equilibrium based on network performance and utility functions according to business relationships, namely, peer, wholesale and retail services. The experimental results show that the equilibrium policy leads ISPs to act as non-selfish behavior under the network objective of blocking probability. Meanwhile, based on the utility functions of business models (i.e. peer, wholesale and retail services), the equilibrium policy leads ISPs to act as a selfish behavior.

I. INTRODUCTION

The Next Generation Networks (NGN) can be seen as an assembly of different autonomous networks operated by separated authorities (multi-operators). In NGN [1], the control intelligence function is embedded to support all types of services over the packet-based transport network. The challenge of providers today exists due to user perspectives. As the subscribers sign contract with a service provider, end-to-end service level agreements (SLAs) of their traffic must be guaranteed. Necessarily, end-to-end SLAs cannot be done without supports from multiple network domains.

In next generation telecommunication industry under deregulatory environment, the providers have the right to freely select their preferred techniques to control their traffic. There are several approaches to cope with the routing decision process. For instance, Border Gateway Protocol (BGP) is the de facto routing protocol employed in the edge routers to construct a connection across domain boundaries. Although BGP supports the distribution of some limited telecommunication engineering information, in practice, BGP only advertises reachable information between domains [2]. No intra-domain information such as path bandwidth utilization, path delay, and path availability is exchanged across the boundaries. Consequently, there are several attempts that have focused on the topic of BGP modification in order to

deliver the required information across domains (e.g. [3], [4], [5]). Obvious drawback of implementing modified BGP is the substantial increase of complexity.

Apart from BGP enhancement, the provisioning policies have been investigated (e.g. [6], [7]). Reference [6] has proposed three policies (i.e. least-effort, most-effort, and equal distribution policies) to cope with the end-to-end SLAs path provisioning in the interdomain network. The concept of the minimum and maximum availability of path selection are assigned for connection request based on the least-effort, and most effort policy, respectively. Additionally, the concept of the equal distribution policy is to separate an equal responsibility with availability target to every domain. The idea of three policies are not to require any knowledge about the internal structure of other domains. Nevertheless, previous investigations have been limited to considering the only case in which all ISPs use the same policy. Therefore, there is no investigation into the freedom of policy selection.

With the aim at studying in an end-to-end SLAs provisioning problem in non-regulated service environment, the equilibrium of interaction between ISPs is investigated. Based on a freedom of policy selection, we propose a technique to capture a generalized path selection policy as the path-classification scheme. Due to interaction between network domains, the game theory is a well suited mechanism to formulate the framework capturing this situation. (e.g., [7],[8],[9], and [10]). Therefore, in this paper, we adopt a game theoretical framework to solve the equilibrium of the game. At the equilibrium, non ISP is willing to change their policy, called the equilibrium policy. In order to capture the providers' interaction behavior, we modified the method of successive average [11] for searching a Nash equilibrium. Further, with the concept of utility function, the equilibrium policy can be analysed to compare different business models (i.e. peer, wholesale and retail services). The performance of network and the network utility are investigated by case studies.

The rest of this paper is organized as follows. Section II introduces the proposed policy-based path provisioning scheme and the description of policy implementation procedure. Section III explains how to transfer the interdomain

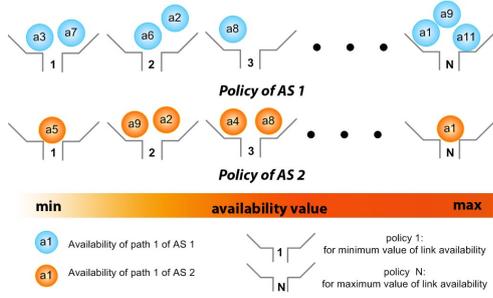


Fig. 1. Proposed policy-based path provisioning

network problem to a game problem. Furthermore, it gives significant details about how an equilibrium policy is solved with the basis on utility functions of three business models, namely peer, wholesale and retail services. The simulation experiments are presented in Section IV. Finally, in Section V, the contributions of this paper are summarized and the future studies are suggested.

II. PROPOSED POLICY-BASED PATH PROVISIONING

With the aim at not requiring any internal network information and not binding any network policy agreement, a generalized policy is proposed in this section.

1) *Key aspect*: Consider a guaranteed service request across multiple network domains. There are two major SLA parameters that must be guaranteed for reliable connection provisioning, namely availability and bandwidth constraints. In this work, the traffic demand is specified for each connection, based on parameter bounds, namely, the maximum bandwidth, the maximum delay, and the minimum availability. When there is a call request across domains, relevant autonomous systems will seek a path and establish a connection to the end user. All possible paths travel through several autonomous systems to its destination. For the purpose of choosing a path which satisfies the SLAs according to the request, Autonomous Systems (ASs) referred to ISPs try to choose the most efficient path in terms of maximum chance of call success and least bandwidth consumption.

2) *Proposed policy*: In practice, the providers have several choices to route from a border router to an adjacent border router. Typically, these choices have a variety of qualitative SLAs in terms of availability value and bandwidth volume which causes hindrance of routing decision. In this work, we proposed an effective technique to manage the diversity of path selection, called a *path-classification scheme*. The paths satisfying both bandwidth and availability constraints are classified into groups according to the obtainable path availability. With $N(d)$ thresholds for network domain d , the autonomous system has $N(d)$ groups of paths as illustrated in Fig. 1.

Let $a(k, d)$ denote the availability of path k in domain d . $K(d)$ is defined as the set of paths which satisfy the constraints including bandwidth target $b_{t,s}$ and availability target $a_{t,s}$ of service type s in domain d . The paths in $K(d)$ are classified into multiple groups. We name the selection

of a path from group $n \in \{1, 2, \dots, N(d)\}$ as *policy n* . Hence, policy n means the selection of paths which satisfy availability values in range $[\tau_{n-1}(d), \tau_n(d)]$ where

$$\tau_n(d) = \frac{\max_{k \in K(d)} \log(a(k, d)) - \min_{k \in K(d)} \log(a(k, d))}{N(d)/n} \quad (1)$$

for a connection original and destination pair and initialized value $\tau_0(d) \triangleq \min_{k \in K(d)} \log(a(k, d))$. We equally separate availability value which presents with the logarithm function in order to take a small different digit of availability magnitude into account.

3) *Policy implementation*: For a convenient way to implement path provisioning strategies based on multi-dimensional constraints, path-classification scheme is applied in the process of AS's path establishment. Assume that there is a call request with targets $b_{t,s}$ and $a_{t,s}$. For constructing a connection, the procedure of path selection is as follows:

- Step 0: Indicate a possible route ($r \triangleq (d_1, d_2, \dots, d_h)$) passing h domains, respectively where d_1, d_2, \dots, d_h indicate a respective sequence of domains from source to destination of the connection request. Start at d_i where $i = 1$.
- Step 1: At d_i , find all possible paths in $K(d_i)$ with bandwidth and availability more than $b_{t,s}$ and $a_{t,s}$. If $K(d_i) = \emptyset$, then the connection will be rejected and the procedure will end.
- Step 2: If $K(d_i) \neq \emptyset$, then classify the paths in $K(d_i)$ into $N(d_i)$ groups according to the availability threshold in (1).
- Step 3: Randomly select a path in $K(d_i)$ within availability rang of policy n . The reason of random is for load balancing over all candidate paths in the selected group. However, if there is no path satisfying the feasible range, then the policy will be relaxed by choosing the path with the maximum availability in policy $n - 1$. Note also that, if $K(d_i)$ is not empty, then policy 1 always contains at least one candidate path.
- Step 4: Update the availability target required for the rest of the path towards the destination: $a_{t,s} := a_{t,s}/a(k, d_i)$ corresponding to the selected path k of domain d_i .
- Step 5: Update i with $i + 1$ in order to indicate the next hop and return to Step 1 until the destination is reached ($i = h$).

According to this framework, despite of many choices in path provisioning, the providers can easily select their preferred policy n from $N(d)$ options for in the call admission control. However, in practice, the ISPs try to adjust their selection to achieve their objectives, such as maximum chance of call success and least bandwidth consumption. Obviously, the ISPs are still facing an uphill task in admission control problem. Hence, it is essential to seek an equilibrium policy to enhance the network performance as well as ISP's satisfactory.

III. EQUILIBRIUM POLICY

A. Interdomain network game

Without strict regulation in NGN service provision, ISPs freely control the traffic in their network by concerning only their objective. Meanwhile, they have no right to control the traffic across domains. This situation is like a free competitive game among ISPs. Thus, we apply a game theory in order to find an equilibrium policy in such an interdomain network problem. A concept of non-cooperative game theory is adopted due to no communication as well as no exchanging of any intra-network information between adjacent domains. As a result, provisioning end-to-end SLA across multiple domains is addressed as a game played among ISPs. To capture the choices of path selection, the path-classification scheme is implemented. All ISPs try to establish the path which satisfy the constraints by selecting a policy n in the provisioning process. The actions of choosing the preferred policy n are the game strategies. The significant key that drives the ISPs to achieve the objectives is the selection of the best policy responsive to the other ISPs. As a mathematical device intended to analyse the game solution, we map the game outcomes by a utility function based on the ISP's objectives.

B. Utility function

The concept of utility function is originally used in economics. It represents the amount of satisfaction of a player towards the outcome. In this paper, a utility function $u(\cdot)$ refers to the satisfaction of ISP's outcomes. We adopt it according to different business models as considered in [6].

- 1) **Peer:** Two adjacent ISPs have an agreement to trade their traffic flow equally. Hence, there is no exchange payment between them [13]. Therefore, only the cost of reserved bandwidth reflects in the utility function. When AS_d applies policy i against policy j of its peer, the utility value of AS_d ,

$$u_d(i, j) = -c_d w_d(i, j) \quad (2)$$

where $w_d(i, j)$ is the reserved bandwidth of domain d which costs c_d unit cost per bandwidth unit.

- 2) **Customer-to-provider:** This business model represents the relationship of a charging fee for exchanging traffic between adjacent domains. There are two different models:

- **Wholesale service:** The provider charges the customers' forwarding traffic in term of demand volume with a flat rate. Thus, the utility function is given by

$$u_d(i, j) = \sum_{s=1}^S g_d \sigma_{d,s}(i, j) - c_d w_d(i, j) \quad (3)$$

where g_d denotes the revenue per connection, and $\sigma_{d,s}(i, j)$ denotes the number of accepted calls of type $s \in \{1, \dots, S\}$ in domain d , when policies i and j are employed by AS1 and AS2 respectively.

- **Retail service:** In contrast to the wholesale service, the revenue of ISP depends on the service type of accepted calls, corresponding to their availability requests. Therefore,

$$u_d(i, j) = \sum_{s=1}^S g_d(a_{t,s}) \sigma_{d,s}(i, j) - c_d w_d(i, j) \quad (4)$$

where $g_d(a_{t,s})$ denotes the revenue per connection depending on the availability request $a_{t,s}$.

C. Nash equilibrium

Due to the nature of interaction between domains, an ISP can learn from the other ISPs' actions and adjust the strategy accordingly. This behavior is similar to sequential actions and reactions between domains. At the end, the strategies are selected with the proper probabilities—so-called *mixed strategies*. For simplification, in this paper, we study a problem of interaction between two domains.

Given the probability p_i for AS1 and q_j for AS2 applied to policies i and j , respectively, the average utilities [12] are obtained from

$$E[U_1] = \sum_{i=1}^l \sum_{j=1}^m p_i q_j u_1(i, j) \quad (5)$$

and

$$E[U_2] = \sum_{i=1}^l \sum_{j=1}^m p_i q_j u_2(i, j). \quad (6)$$

Note that $\sum_{i=1}^l p_i = 1$ and $\sum_{j=1}^m q_j = 1$ with l and m policies for AS1 and AS2, respectively. Suppose that $E[U_1^*]$ and $E[U_2^*]$ received from applying probability vectors $(p_1^*, p_2^*, \dots, p_l^*)$ and $(q_1^*, q_2^*, \dots, q_m^*)$ to (5) and (6). $E[U_1^*] \geq E[U_1]$ and $E[U_2^*] \geq E[U_2]$ for all vector (p_1, p_2, \dots, p_l) and (q_1, q_2, \dots, q_m) if, and only, if $(p_1^*, p_2^*, \dots, p_l^*)$ and $(q_1^*, q_2^*, \dots, q_m^*)$ are said to be Nash equilibrium. Therefore, by means of Nash equilibrium in mixed strategy game, the equilibrium policy in interdomain network problem can be achieved.

D. Nash equilibrium by Method of Successive Average

To find a Nash equilibrium in a game, one must search in the space of (p_1, p_2, \dots, p_l) and (q_1, q_2, \dots, q_m) . In this work, we modify the MSA [11] to search for a Nash equilibrium point by adjusting the calculation of expected utility of each player. The detail of computational steps are demonstrated as follows.

Step 0: Initialize probability (p_1, \dots, p_l) and (q_1, \dots, q_m) to $1/l$ and $1/m$, respectively. And set $n = 1$ where n denotes the current iteration number.

Step 1: Find the strategy \hat{i} which maximizes the utility of AS1 :

$$\hat{i} = \arg \max_{i \in \{1, \dots, l\}} \left\{ \sum_{j=1}^m p_i q_j u_1(i, j) \right\}.$$

Step 2: Set $x_i = 1$ if strategy i is selected ($i = \hat{i}$) and 0 otherwise.

- Step 3: Update the probability of strategy of AS1: $p_i \leftarrow (1/n) \cdot x_i + (1 - (1/n)) \cdot p_i$ for all i .
- Step 4: Find the strategy \hat{j} which maximizes the utility of AS2 :

$$\hat{j} = \arg \max_{j=\{1,\dots,m\}} \left\{ \sum_{i=1}^m p_i q_j u_2(i, j) \right\}.$$

- Step 5: Set $y_j = 1$ if strategy j is selected ($j = \hat{j}$) and 0 otherwise.
- Step 6: Update the probability of strategy of AS2: $q_j \leftarrow (1/n) \cdot y_j + (1 - (1/n)) \cdot q_j$ for all j .
- Step 7: Update the iteration number $n \leftarrow n+1$ and return to Step 1 until the utilities computed from (5) and (6) converge.

Note that, in Steps 1 and 4, if there is more than one possible solution, then we randomly select the corresponding strategies in a uniform manner. At the end of this process, the Nash equilibrium is found.

IV. NUMERICAL EXPERIMENTS

In non-regulated environment, the numerical experiments by using MATLAB program have been to study path-classification schemes. We search Nash equilibrium based on the utility function by the modified MSA. The results from Nash equilibrium, is compared with the least-effort, the most-effort and the equal distribution policies as proposed in [6]. We present the simulation results in two directions. Firstly, the network performance have been investigated from both blocking probability and bandwidth usage. Secondly, the utilities of three business relationship models have been considered.

A. Simulation environment

According to peering conditions [13], such as equal traffic exchange and comparable network size of two domains, in this simulation, we constructed network environment on two symmetrical domains as illustrated in Fig. 2. Assume that each domain consists of eight possible paths containing OC-192 (9.952 Gbps) each. In order that the range of path availabilities covers all service types, the availability values of paths are assumed as demonstrated in Table I.

As for the connection properties, each call request is associated with the origin and the destination in AS1 and AS2 which are randomly selected with equal probability. We assume Poisson arrival of each call and exponentially distributed call holding times for all experiments. All results have been investigated with the effect of loading by changing total offered load from 15 Erlangs to 240 Erlangs at a constant mean holding time of 30 sec. The characteristics of incoming demands are demonstrated in Table II

To illustrate the problem of path-classification scheme, for case studies, we set $N(d) = 3$ for all domains, so that all ASs have the same number of strategies. Policies 1, 2 and 3 refer to paths in a group of low, middle and high availability ranks. The performance results presented as a function of load are measured durring the steady state.

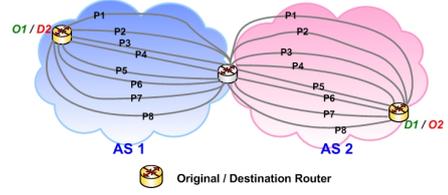


Fig. 2. Interdomain network for simulation

TABLE I
PATH AVAILABILITY

Path number	Availability (%)	Capacity (Gbps)
1	99.999	9.952
2	99.998	9.952
3	99.991	9.952
4	99.987	9.952
5	99.95	9.952
6	99.85	9.952
7	99.75	9.952
8	99.60	9.952

B. Performance evaluation

Call blocking probability of the network is set to be the objective of ASs. Fig. 3 shows an example of how to find a Nash equilibrium policy by injecting offered load 30 Erlangs into the system. The policy $[n_1, n_2]$ denotes policy n_1 implemented for AS1 and policy n_2 implemented for AS2. In Fig. 3 (a), the best response policy of AS1 given policies 1, 2 and 3 of AS2 is policy 3. Similarly, in Fig. 3 (b), the best response policies of AS2 given policies 1, 2 and 3 of AS1 are policy 3, 2 and 3 respectively. As a result, in this case, the equilibrium policy is found at policy [3,3]. In the other words, both AS1 and AS2 do not willing to change their policy from 3 to the other policies.

For comparative study of the performance, we report the results of blocking probability in term of traffic grouping by bandwidth and availability targets of the call requests. Fig. 4 shows that the bandwidth requirement is a major effect on overall blocking probability. Moreover, it depicts that the highest blocking probability is found in the group of large bandwidth and high availability requests ($b_{t,s} \geq 155.5$ Mbps, $a_{t,s} \geq 99.98\%$). The reason is that there are few routes which can support availability over than 99.98%. When we

TABLE II
TRAFFIC PARAMETERS AND DISTRIBUTION

Parameters	Service level	Probability distribution
Maximum bandwidth	1.544 Mbps	35%
	44.736 Mbps	30%
	155.52 Mbps	20%
	622.08 Mbps	10%
	2.448 Gbps	5%
Connection availability	99.99%	25%
	99.98%	40%
	99.91%	25%
	90%	5%
	80%	5%

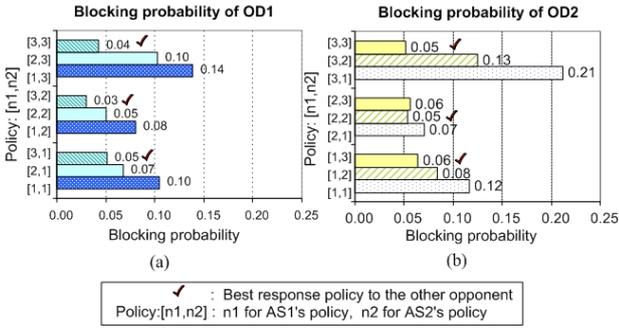


Fig. 3. Blocking probability of demand OD1 and OD2 according to policy: $[n_1, n_2]$: the results from offered load 30 Erlangs.

compare four policies, the least-effort and equal distribution policy also yields higher blocking probability than the most-effort policy and Nash equilibrium. Due to a selfish manner of the least-effort policy, the blocked calls are very high because at least one domain cannot provide paths according to the requirement constraints. However, it is not the same reason as the equal distribution policy. The equal distribution policy yields high blocking probability because the path choices are restricted to the equal threshold even though a little flexibility of the threshold exists. In addition, Nash equilibrium provides the results similar to the most-effort policy because Nash equilibrium is policy [3,3].

Fig. 5 shows the bandwidth usage of the system. The most-effort policy and Nash equilibrium provide high bandwidth usage which contradicts the least-effort and equal distribution policy relating to the blocking probability. Note that, the equal distribution policy provides non-increasing bandwidth usage as the offered load increase. It means that, with this policy, the calls could not be accepted any more into the system when the load is increasing. The results from Nash equilibrium is slightly different the most-effort policy because of the uniformly random selection.

For setting the performance as a network objective, we can see that the equilibrium of a free play environment is good for the users. That is all ISPs drive the system to the non-selfish behavior.

C. Profit of three business models

In this simulation, we set the ISPs' objective according to the profit of three business models. For peer service model, the utility function in (2) implies that high bandwidth usage causes low utility. Fig. 6 presents that the least-effort policy, Nash equilibrium and equal distribution yield high utilities. On the other hand, the utility from the most-effort policy is very low. Note that, the utility from Nash equilibrium is close to least-effort policy because the equilibrium solution is policy [1,1].

For wholesale service model, the utility of ISPs depends on a revenue term and a cost term as shown in (4). The results are reported in two cases. First, the revenue term is comparable with the cost term as demonstrated in Fig. 7 (a). The utility from the least-effort, equal distribution policy and Nash equilibrium decline in very light load. However, they

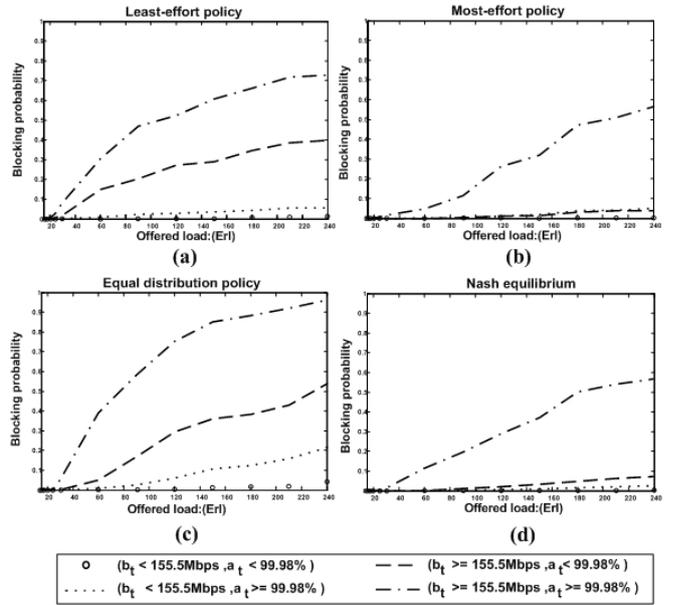


Fig. 4. Blocking probability comparison among four groups of traffic types. (a) Least effort policy, (b) Most-effort policy, (c) Equal distribution policy and (d) Nash equilibrium

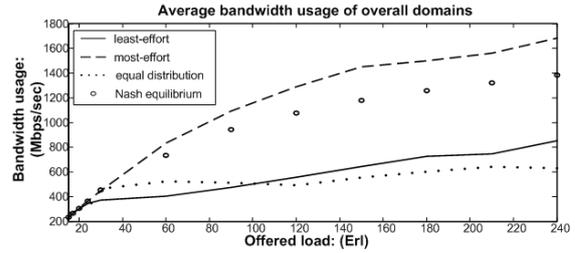


Fig. 5. Bandwidth utilization of the network.

rebound at load 30 Erlangs. In contrast to the others, the utility of the most-effort policy falls gradually at light load but remains stable at high load. The fact is that, amount of high bandwidth connections are more accepted than other policies. The results of Nash equilibrium is close to least-effort policy because the solution is policy [1,1]. Second, the revenue part dominates the cost part as demonstrated in Fig. 7 (b). All utilities rise sharply relating to increasing load. In this case, Nash equilibrium also is policy [1,1].

For retail service model, we assume the charge rate per connection is a function of availability ($g(a_{t,s}) = 6000 * a_{t,s}(\%)$). The minimum charge rate is equal to the flat rate of the wholesale model in Fig. 7. We can see that the utilities from the retail service model are more than the utility from the wholesale service. The Nash equilibrium of this model is the same solution as the wholesale service. That is policy [1,1] is the equilibrium solution.

Here, the contribution of this paper is emphasized. If ISPs concern the blocking probability, the equilibrium policy is policy [3,3] which is very close to the most-effort policy. However, the results from three utility functions imply that the equilibrium of the interdomain network problem in free

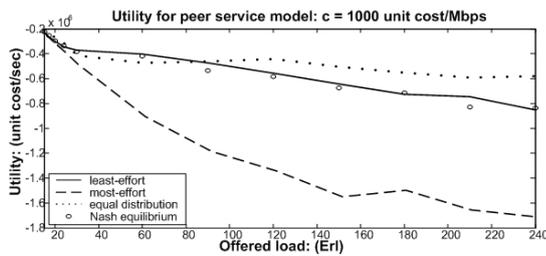


Fig. 6. Utility of peer-to-peer model: $u_d(i, j) = -c_d w_d(i, j)$ where $c = 1000$ unit cost per Mbps.

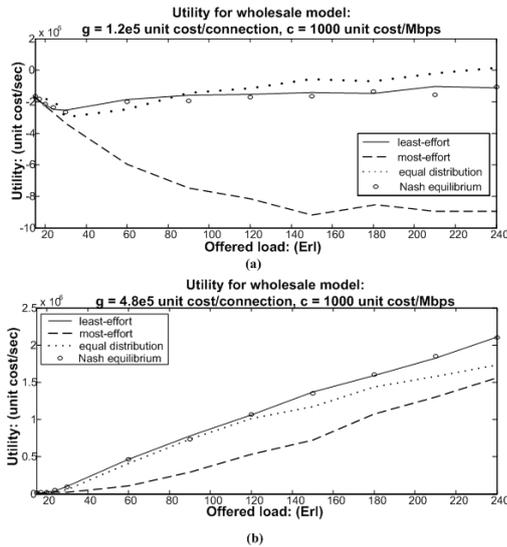


Fig. 7. Utility of wholesale service model: $u_d(i, j) = \sum_s^S g_d \sigma_{d,s}(i, j) - c_d w_d(i, j)$. (a) $c = 1000$ unit cost per Mbps and $g_d = 1.2e5$ unit cost per connections and (b) $c = 1000$ unit cost per Mbps and $g_d = 4.8e5$ unit cost per connection.

regulated environment converges to the least-effort policy. It means that, instead trying their best, ISPs try to take an selfish action to the others as much as they can do. Thus, the QoS protection for users is necessary. The penalty part such as QoS should be taken in to account in the utility function.

V. CONCLUSION

In this paper, we focus on the problem of providing end-to-end SLAs in the interdomain networks. We propose the path-classification scheme to decrease diversity of the path selection. With this scheme, we can map aims of ISPs' decisions into many categories. For studying the ISPs interaction in the free regulation environment, the mixed strategy of game theory is applied in this problem. We adopt MSA with Nash equilibrium as a tool for seeking the equilibrium policy. The performance evaluation based on blocking probability shows that the equilibrium policy is [3,3] which is very close to the least-effort policy. On the other hands, by considering the utility according to the three business models, policy [1,1] is the equilibrium solution. Hence, without QoS consideration, the solution leads to the selfish behavior. Therefore, in our suggestion, the QoS penalty in term of blocking probability

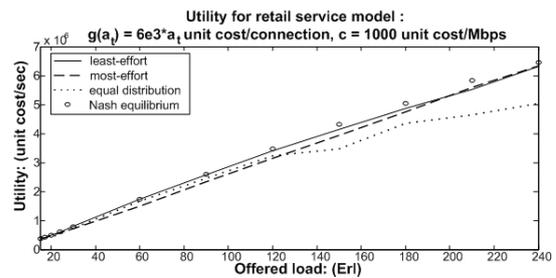


Fig. 8. Utility of retail service model: $u_d(i, j) = \sum_s^S g_d(a_{t,s}) \sigma_{d,s}(i, j) - c_d w_d(i, j)$ and charge: $c = 1000$ unit cost per Mbps and $g_d(a_{t,s}) = 6e3(a_t)$ unit cost per connection

should be added into the utility function. For the future work, an analytical model will be studied including the penalty term. Additionally, the negotiation across domains will be investigated, such as a crank-back mechanism. Furthermore, we will extend the proposed scheme to flexibly use across different business model.

VI. ACKNOWLEDGEMENT

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