Game-theoretic approach to prevent selfish path provisioning in interdomain networks

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Abstract—Recently, SLAs become an important issue considered in the next generation telecommunication services. The subscribers’ perspective drives ISPs eager to support their requirements by offering SLAs across domains. Under deregulatory environment, this paper has adopted a path-classification scheme in order to capture the freedom of policy selection. To prevent selfish path provisioning in the interdomain network, we propose the utility function that includes the penalty term. 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 the proposed 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 and to achieve high system performance.

I. INTRODUCTION

Service Level Agreements (SLAs) recently become a key issue in the next generation telecommunication services as it can be seen in various telecommunication regulatory documents, e.g. [1]. Due to growing concern of subscribers about SLAs (e.g. minimum path availability, maximum bandwidth), Internet Service Providers (ISPs) are trying to seek a beneficial scheme to keep their promises respecting to the service requests.

Focusing on the connection-oriented services based on MPLS/GMPLS in the interdomain network, ISPs are facing with challenges of twofold problem. The majority problem is how to provide end-to-end SLAs paths according to the subscribers’ requests in the interdomain network. End-to-end SLAs cannot be done without coordination from multiple network domains. Several previous researches have proposed schemes to deal with this need. For example, adopting BGP at the edge routers is a typically useful technique to construct an end-to-end connection across the multiple domains [2],[3]. The key idea of these works is to achieve the end-to-end SLAs services by extending BGP to include Traffic Engineering (TE) information across domain boundaries.

Besides the modified BGP approaches, several researches have investigated the path provisioning policies to overcome the problem of end-to-end SLAs during a path establishment (e.g. [4]–[6]). Three policies, i.e. least-effort, most-effort and equal-distribution policies, have been proposed in [5] with the concept of minimum, maximum and equal responsibility in term of path availability effort. With these policies, the ISPs do not necessarily require internal TE extension across domains. However, the freedom of policy selection is not held. Instead of forcing all domains to execute the same path selection policy, reference [6] has proposed the idea of letting ISPs freely select a path according to their own “path-classification” scheme. In addition, [6] has shown that, in practice, game-theoretical approach drives the system to achieve the equilibrium point. However, one drawback of using the utility function of three business models (i.e. peer, wholesale, retail models) referred in [6] is that the equilibrium point leads to selfishness.

Clearly, the selfish behavior cannot drive the system to satisfy the subscribers as well as the other operators in the same network [7], [8]. Therefore, another challenge to ISPs is to prevent the impact of the other ISPs’ selfishness. There are several researches (e.g. [7], [8]) which adopt the concept of penalty to punish selfish operators. Consequently, we take into account the penalty function in this paper.

We address our studies to overcome the end-to-end SLAs path provisioning problem in a free-regulatory network environment and to prevent selfish path provisioning. In this paper, we have adopted the path-classification scheme proposed in [6] to broaden the policy selection for the end-to-end SLAs path provisioning. Moreover, we have proposed the utility function that includes the penalty term to prevent the selfishness. Then, we have investigated the equilibrium point of this problem using game theory by means of Nash equilibrium via modified Method of Successive Average (MSA) [6]. The equilibrium policies of three business models are analysed with the proposed utility function. The comparison of system performance among different policies have been investigated.

The rest of this paper is organized as follows. Section II presents the problem formulation and motivation. The penalty function is proposed in Section III. In Section IV, we propose the utility function applied to three business models, i.e. peer model, wholesale model and retail model, and, then, describes the game theoretic approach. Numerical experiments are presented and their results are discussed in
Section V. Finally, conclusions are drawn in Section VI.

II. PROBLEM FORMULATION AND MOTIVATION

Based on connection-oriented services in the interdomain network, we consider an end-to-end path provisioning problem with respect to SLA parameters, namely availability and bandwidth constraints. In this paper, we assume that each ISP has only one Autonomous System (AS). Then, from here, the term AS refers to an ISP throughout this paper.

Assuming that the traffic demand is specified for each connection, based on parameter bounds, namely, the maximum bandwidth and the minimum availability. Basically, when a connection request occurs, the relevant ASs will seek a possible path for the connection establishment. We adopt the path-classification scheme [6] to reduce the diversity of path selection in this paper. 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. Let \( a(k,d) \) denote the availability of path \( k \) in domain \( d \). \( K(d) \) is defined for domain \( d \) as the set of paths which satisfies the constraints including bandwidth target \( b_{t,s} \) and availability target \( a_{t,s} \) of service type \( s \). The paths in \( K(d) \) are classified into multiple groups. The selection of a path from a group \( n \in \{1,2,\ldots,N(d)\} \) is called policy \( n \). Hence, policy \( n \) means the selection of paths which satisfy availability values within the interval \((\tau_{n-1}(d),\tau_n(d))\) where [6]

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

and the initialized value \( \tau_0(d) \triangleq \min_{k \in K(d)} \log (a(k,d)) \).

Obviously, the ISPs can use the path-classification scheme to help them provision their traffic routes. The ASs just select the preferred policy \( n \) for routing management. However, this scheme does not prevent occurrences of an extremely selfishness policy selection. As we realize from the results in [6] that setting the utility function according to only maximum network profit and minimum network cost could not prevent the selfish path provisioning. In the other words, these results show that all operators prefer a path that minimizes its own bandwidth consumption and offers the least possible availability as its promised SLA during a connection establishment at a burden of other ISPs that have not yet specified their promised SLAs. Therefore, the idea of penalty function is introduced to prevent the selfishness.

III. PROPOSED PENALTY FUNCTION

End-to-end path establishment is generally constructed as a sequence of provided paths from the origin to the destination. End-to-end path establishment may not succeed with its requested SLA if any previous AS provides very low availability path. Therefore, the rest of ASs could not seek a path that satisfies the availability constraint although any path in these domains have enough remaining bandwidth for the call request. We, then, clarify this behavior as a selfish path provisioning. Hence, the penalty function is defined in terms of how much the regulator punishes the ASs who selfishly provision their paths. The concept of penalty is summarized in Fig. 1. With this definition, we can mathematically formulate the penalty function based on consideration of two ASs as

\[
\Upsilon_d = f_d \gamma_d(i,j) \tag{2}
\]

where penalty factor \( f_d \) represents penalized level per connection of domain \( d \) and \( \gamma_d(i,j) \) be a number of rejected connections with the result that the rest of ASs along the explicit route could not find any path met the availability constraint when AS\(_d\) applies policy \( i \) against policy \( j \) of its peer.

IV. UTILITY FUNCTION AND GAME-THEORETIC APPROACH

In this paper, we propose the utility function \( u(\cdot) \) to represent the overall ISP satisfaction which consists of a revenue function, a cost function and a penalty function.

Three utility functions according to three business models as considered in [5], namely peer, wholesale and retail models are as follows.

A. Peer model

Two adjacent ISPs have an agreement to trade their traffic flow equally. Hence, there is no exchange payment between them. The cost function depends on the amount of reserved bandwidth \( w_d \) and cost value \( c_d \) unit cost per bandwidth unit. Hence, the cost function equals to \( c_d w_d(i,j) \). Therefore, the utility value of \( A_S \),

\[
u_d(i,j) = -c_d w_d(i,j) - f_d \gamma_d(i,j) \tag{3}
\]

B. Customer-to-provider model

There are two different services which charge fee for exchanging traffic between adjacent domains.

- Wholesale service: The provider charges the customers’ forwarding traffic in terms of demand volume with a flat rate. Thus, the revenue function of wholesale model is represented by \( \sum_{s=1}^{S} g_d \sigma_{d,s}(i,j) \) where \( g_d \) denotes the revenue per connection, and \( \sigma_{d,s}(i,j) \) denotes the number of accepted calls of type \( s \in \{1,\ldots,S\} \) in domain \( d \), when policies \( i \) and \( j \) are employed by AS\(_1\) and AS\(_2\) respectively. Hence, the utility function is given by

\[
u_d(i,j) = \sum_{s=1}^{S} g_d \sigma_{d,s}(i,j) - c_d w_d(i,j) - f_d \gamma_d(i,j) \tag{4}
\]
• 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,

\[ u_d(i, j) = \sum_{s=1}^{S} g_d(a_{ts}) \sigma_d(i, j) - c_d w_d(i, j) - f_d \gamma_d(i, j) \]

where \( g_d(a_{ts}) \) denotes the revenue per connection depending on the availability request \( a_{ts} \) with respect to service type \( s \).

C. Game-theoretic approach

Due to the nature of interaction between domains, an AS can learn from the others ASs’ 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. By means of Nash equilibrium in mixed strategy game, the equilibrium policy in interdomain network problem can be achieved. In this work, we adopt modified MSA [6] to search for a Nash equilibrium point. The detail of computational steps are demonstrated in [6]. Therefore, the equilibrium policy based on the proposed utility function can be found.

V. NUMERICAL EXPERIMENTS

In this paper, we present a preliminary investigation of selfish path provisioning in interdomain network with two ASs. To illustrate the effectiveness of the proposed utility function, we set the numerical experiments based on MATLAB programming. The results from the equilibrium policy based on the path-classification scheme by searching Nash equilibrium using the modified MSA [6] are compared with the with the least-effort, the most-effort and the equal distribution policies as proposed in [5]. We investigate how the proposed utility function can prevent selfish path provisioning. Moreover, the utilities of three business relationships (i.e. peer, wholesale and retail) have been considered.

A. Simulation environment

According to peering conditions, 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. Each domain consists of eight possible paths each with OC-192 (9.952 Gbps). To have the range of path availabilities covers all service types, the availability values of paths are demonstrated in Table I [6].

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 [6].

<table>
<thead>
<tr>
<th>Path number</th>
<th>Availability (%)</th>
<th>Capacity (Gbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>99.999</td>
<td>9.952</td>
</tr>
<tr>
<td>2</td>
<td>99.998</td>
<td>9.952</td>
</tr>
<tr>
<td>3</td>
<td>99.991</td>
<td>9.952</td>
</tr>
<tr>
<td>4</td>
<td>99.987</td>
<td>9.952</td>
</tr>
<tr>
<td>5</td>
<td>99.95</td>
<td>9.952</td>
</tr>
<tr>
<td>6</td>
<td>99.85</td>
<td>9.952</td>
</tr>
<tr>
<td>7</td>
<td>99.73</td>
<td>9.952</td>
</tr>
<tr>
<td>8</td>
<td>99.60</td>
<td>9.952</td>
</tr>
</tbody>
</table>

To illustrate the problem of path-classification scheme, 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 results presented as a function of load are measured during the steady state.

B. Numerical results

We give an example of preventing selfish path provisioning test via adopting the utility function of peer model. Fig. 3 illustrates the call blocking probability of the network with the comparison of five different policies, i.e. the least-effort, most-effort, equal distribution policies, equilibrium policy without the penalty function (e-policy without penalty) and equilibrium policy with the penalty function (e-policy with penalty). Based on the peer model, the results show that e-policy with penalty provides call blocking probability lower than the results from e-policy without penalty. Additionally, they also are close to the results from most-effort policy in light load except for heavy load. We observe that including the penalty term in the utility function can force the system to reach the unselfishness. However, the effects depend on the level of penalty \( (f) \) and traffic demand.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Service level</th>
<th>Probability distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum bandwidth</td>
<td>1.544 Mbps</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>4.4736 Mbps</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>155.52 Mbps</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>622.08 Mbps</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2.448 Gbps</td>
<td>5%</td>
</tr>
<tr>
<td>Connection availability</td>
<td>99.99%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>99.98%</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>99.91%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5%</td>
</tr>
</tbody>
</table>
Fig. 3. Comparison of overall call blocking probability: in the case of using utility of peer-model

Fig. 4. Comparison of utility of peer model: where \( c_d = 1000 \) unit cost per Mbps and \( f_d = 1000 \) unit cost per connection

Fig. 5. Comparison of utility of wholesale model: where \( c_d = 1000 \) unit cost per Mbps, \( g_d = 6 e 6(\alpha_l) \) unit cost per connection and \( f_d = 1000 \) unit cost per connection

Fig. 6. Comparison of utility of retail model: where \( c_d = 1000 \) unit cost per Mbps, \( g_d = 6 e 6(\alpha_l) \) unit cost per connection and \( f_d = 1000 \) unit cost per connection

Fig. 4–Fig.6 show the utility of the network according to peer, wholesale and retail models, respectively. We notice that the system can achieve the high utility by using the e-policy with penalty. The results from wholesale and retail also show that the penalty term causes low utility of least-effort and equal distribution. We clearly see that taking into account the penalty function in the utility function provide the system much better in the terms of preventing the selfishness.

VI. CONCLUSION

In this paper, we study the problem of SLAs end-to-end path provisioning in the interdomain network. To decrease the complexity of path diversity, the path-classification scheme has been adopted in this work. In addition, we have proposed the utility function with the penalty term to prevent

the selfish path provisioning. Under non-cooperative situation as the individual autonomous system, we can apply the concept of game theory for searching the equilibrium point. With modified MSA, the equilibrium policy can be achieved respect to the utility function. In the numerical experiments, we observe that including the penalty term in the proposed utility function can force the system players (ISPs) to become unselfish. Furthermore, the results show that the equilibrium policy based on the proposed utility function can provide the highest network utilities in wholesale and retail model. However, all results depend on the setting parameters such as the level of penalty, cost and amount of profit. For the future works, the effect of these parameters should be investigated. Moreover, the investigation will be extended for more than two domains.

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