

A Study of Bilateral Settlement Game for Differentiated Qualitative Services Networks

Ying-Ren Chien¹, Chien-Sheng Chen², and Wen-Hsiung Liu³

Integrated System Lab, NTU, Taipei, Taiwan¹

Department of Information Management, Tainan University of Technology²

Department of Air Transportation Management, Aletheia University³

E-mail:curtis.chien@gmail.com¹, t00243@mail.tut.edu.tw², whliu@mt.au.edu.tw³

Abstract—For providing end-to-end differentiated service, networks service providers need to interconnect with other service provider and hence such interconnection brings settle problems. Based on the differentiated service network architecture, the new challenges of the settlement problem are how to model the user's demand function and how to allocate the bandwidth resources between inter-domain and intra-domain users. The bandwidth allocation problem becomes more complicated. This paper formulates the settlement problem as a multi-stage game with incomplete information and develops a two-stage solution. In the first stage, we obtain the capacity of Internet bandwidth and the expected total profit by using sequential quadratic programming (SQP) method. In the second stage, continuing the statement regards as the adjustment method of settlement rate. According to the non-linearity and non-convexity of the objective function, we observe there are many Nash equilibrium points in the system. Therefore, the solution to the problem is not unique. Numerical analysis shows that ISP will judge the marginal profit from users and the other interconnected service provider to determine the bandwidth allocation.

Index Terms—Differentiated Services (DiffServ), quality of service (QoS), Game theory, sequential quadratic programming (SQP).

I. INTRODUCTION

The differentiated service (DiffServ) network [1], [2] has been proposed to provide multiple quality-of-service (QoS) classes over IP networks. The traffic is forwarded using simple differentiated treatments in the core of the IP network by labeling per-hop behaviors (PHBs) tags in the IP packets, in which Expedited Forwarding (EF) [3] and Assured Forwarding (AF) [4] labels are defined for providing quantitative and qualitative services, respectively. Interconnection is inevitable to provide end-to-end networking service with QoS [5] and interconnection settlement issues are becoming more significant. Settlement is a contract between peering parties. It can be thought of as payments or financial transfers between Internet Service Providers (ISPs) in return for an interconnection and interoperability. The ISP will charge for end users and pay its peering ISP, however, how to settle the outlay is an important issue. Based on the differentiated service network architecture, the new challenges of settlement problem are user's demand function, the bandwidth allocation problem and the value of bandwidth become more complex.

Game Theory provides a mathematical model to study situations of strategic interdependence where there exists vary-

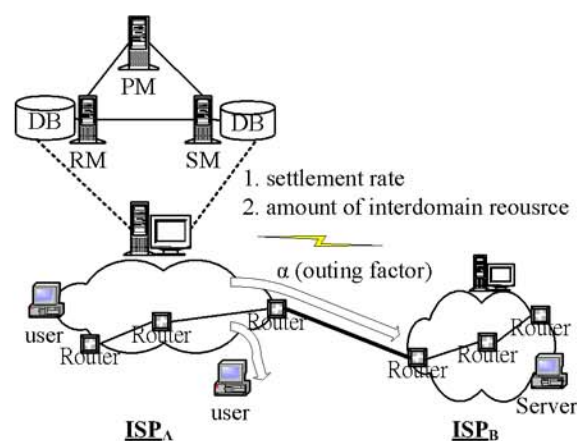


Fig. 1. Model of two interconnected-ISP

ing degree of conflict and cooperation [6]. Game theoretic concepts apply whenever the actions and the outcomes of these actions are interdependent among several parties who may be individuals, groups, or any combination.

This paper focuses on bilateral settlement problem, which concerned about the design of tariff and the capacity of Internet bandwidth. The tariff can be divided into intra-domain domestic tariff and inter-domain settlement rate. Inter-domain settlement rate on sending and receiving side dose not certainly symmetry. We adopt the INDEX (Internet Demand Experiment) project [7] which regresses the demand function of end user to quantify the relationship between domestic tariff and the connection time of transfer service on different classes. Let the probability a user chooses the specific service class is the proportion of the connection time of a class to the total connection time. Moreover, if the demand percentage of outbound traffic is given, the relationship between demand of Inter-domain bandwidth and domestic tariff structure can be established. We adopt negotiation method to determine the settlement rate. Each ISP in turns plans to buy the capacity of Inter-domain bandwidth and price the settlement rate to maximize expected total revenue. In the process, both ISPs negotiate and reach an agreement when there is no one changes decision unilaterally.

II. SYSTEM MODEL

For simplicity, we assume that each ISP provides K different qualitative services and consider only two ISPs are interconnected. Fig. 1 presents a model of two interconnected-ISP. Note that α is outing factors. Each ISP has a policy manager (PM), a resource manager (RM), and a service manager (SM) to provide AF service to end user and to negotiate with its peering party. The PM determines the resource allocation, the corresponding tariff, and over-provisioning factors such that the profit of the ISP is maximized. The over-provisioning factor is used to differentiate the level of assurance for different qualitative services. The larger value of the higher assured service level that a user can expect to has. The SM manages the billing and accounting database (DB) in which user account, service level specification, connection time measurement, amount of connection, and fee amount are recorded. The RM is used for call-admission control (CAC), router control, and service level mapping.

A. Trading model

The trading mechanism of business-to-business (B2B) and business-to-customer (B2C) are illustrated in Fig. 2(a) and (b), respectively. First, the local SM iteratively negotiate with the remote SM (belongs to the other ISP) according to the PM's instruction. This negotiation process determine the amount of the reserved inter-domain bandwidth for each service class and the associated settlement rate. The PM will compute the tariff according to the two values and the local demand from the end-user to maximize its own profit. It also send the commands to the RM to set the relevant parameters in the router so that the services are differentiated.

Next, end-users will determine which service level is the best choice according to the tariff. The end-user submit a service request to the SM. Then the SM will ask the RM if the required resource is available or not, i.e. perform the CAC. The end-user will be charged by the connection time and the service level.

B. User's Demand model

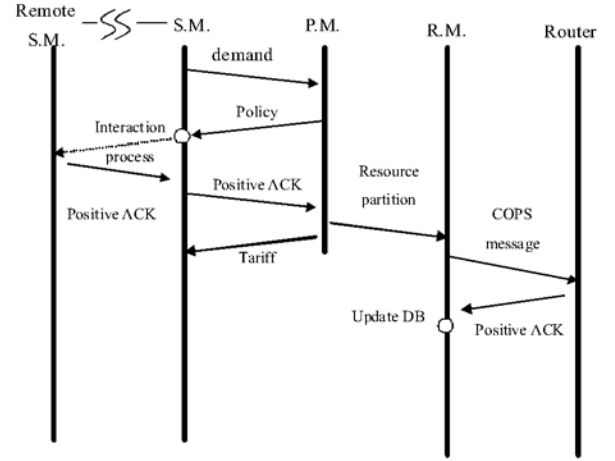
User can be classified into two types. One is the end-user the other is the interconnected ISP. The relationship between connection time and the tariff can be expressed as [7]:

$$\log X_i = b_i + \sum_{j=1}^K a_{ij} \log P_j, \quad (1)$$

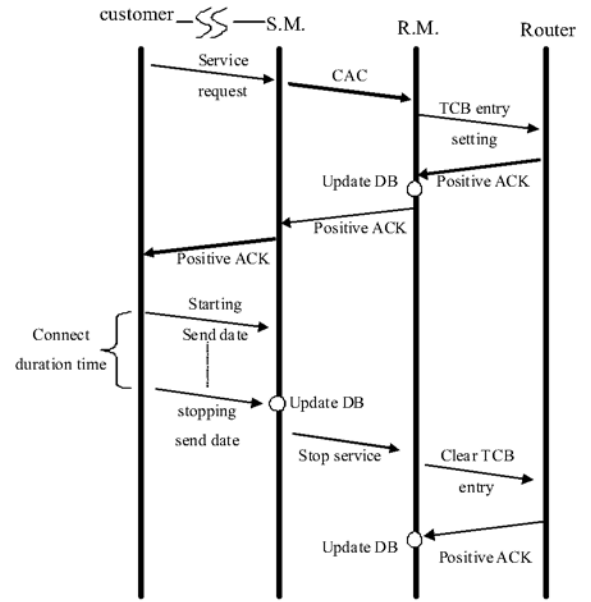
where X_i is the regular connection time (minutes/week) for the i th service level for each user; a_{ij} denotes own-price and cross-price elasticity constant for $i = j$ and $i \neq j$, respectively; K denotes the number of different service levels; P_j denotes the tariff for the j th service level.

III. PROBLEM FORMULATION

Without loss of generality, we formulate the objective function and constraints for ISP_A . Similar formulation can



(a)



(b)

Fig. 2. Timing sequence for (a) B2B and (b) B2C trading models

be used for the other ISP. In order to provide the end-to-end connectivity, an ISP_A has to obtain enough inter-domain resource d_A^B from its peering ISP, i.e. ISP_B .

For the ISP_A , it will maximize the expected total profit J_A subjects to four constraints. J_A is defined by

$$J_A = \sum_{s=1}^K (\lambda T \phi_s + N_s) P_s X_s n + (P_A^B d_B^A \beta_A) T * 60 - (P_B^A d_A^B \beta_B) T * 60, \quad (2)$$

where λ is the average rate of service request (times/min), T is the calculation interval, ϕ_s is the probability that a user will choose the s th service level under the tariff P_s (dollar/min), N_s is the number of user who have already chosen the s th service

level, P_A^B is the settlement rate that ISP_A wants ISP_B to pay, d_B^A is the amount of inter-domain bandwidth requirement that ISP_B wants ISP_A reserved, and β_A is the overprovisioning factor for ISP_A . Base on (1), we estimate ϕ_s as follows:

$$\phi_s = \frac{X_s}{\sum_{s=1}^K X_s}. \quad (3)$$

Due to the limited resources, this object function is subjected to the following constraints C_1 to C_4 .

C_1 Resource constraint

$$c_A/\beta_A \geq \left\{ \sum_{s=1}^K (\lambda T \phi_s + N_s) r_s X_s n \right\} / T + d_B^A, \quad (4)$$

where c_A is the total bandwidth that ISP_A dedicates to the qualitative service, β_A is the over-provisioning factor, and r_s is the rate of the s th service level (KB/sec).

C_2 Profit constraint

$$P_B^A d_A^B T' \leq \left\{ \sum_{s=1}^K (\lambda T \phi_s + N_s) P_s X_s n \right\} \alpha_A, \quad (5)$$

where $T' = 60T$ is the connection time with unit seconds.

C_3 Fairness constraint

$$P_i \leq P_j, \forall i \leq j \in [1, \dots, K] \\ \text{with } P_i = r_i \theta_i p_A \quad (6)$$

where θ_i is the discount factor and p_A is the base price. This constraint means the price of the higher assured service is never less than that of the lower assured service.

C_4 Inter-domain bandwidth reservation constraint

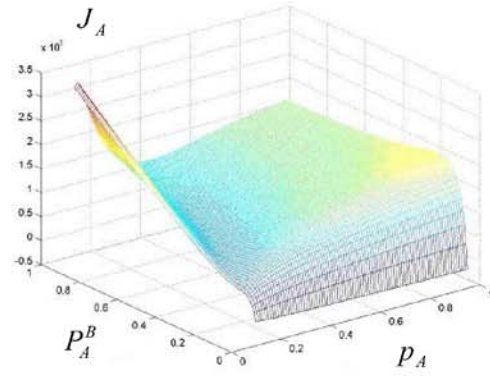
$$d_A^B = \alpha_A \left\{ \sum_{s=1}^K (\lambda T \phi_s + N_s) r_s X_s n \right\} / T \quad (7)$$

Therefore, the optimization problem for ISP_A can be expressed as:

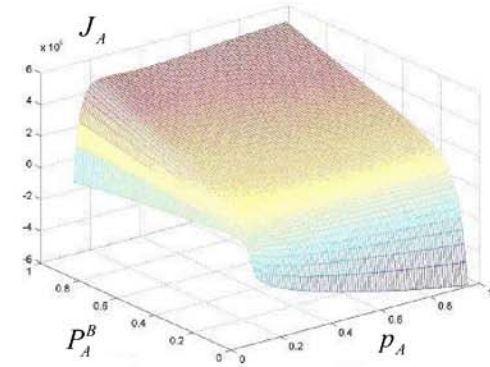
$$\begin{aligned} \text{Max}_{p_A, \theta_i} \quad & J_A(P_A^B, P_B^A, p_A, d_B^A, \beta_A, \beta_B, \theta_i) \\ \text{subject to} \quad & C_1 - C_4 \end{aligned} \quad (8)$$

IV. PROPOSED ITERATIVE ALGORITHM FOR THE MULTI-STAGE GAME WITH INCOMPLETE INFORMATION

Because every ISP has its own profit function, it has no knowledge about the other ISP. Therefore, the negotiation process can be modeled as a game with incomplete information. First, we observe the properties of the objective function J_A has non-linearity, non-convexity, and Inseparability as shown in Fig 3, where the user's elasticity constants are $b_1 = 2.6$, $a_{11} = -3.34$, $a_{12} = 1.23$, $b_2 = 4.1$, $a_{21} = 0.44$, and $a_{22} = -1.65$. Therefore, we propose an iterative reaction strategy to address this optimization problem. The proposed algorithm and the associated reaction strategy are shown in



(a)



(b)

Fig. 3. The relationship among expected profit J_A , settlement rate P_A^B , and domestic tariff p_A . (a) $d_B^A = 200$ KB/sec and $P_B^A = 3.3 \times 10^{-3}$ (b) $d_B^A = 300$ KB/sec and $P_B^A = 6.67 \times 10^{-3}$; other parameters are $T = 360$ mins, $\beta_A = 1$, $\alpha_A = 0.4$, $c_A = 1500$ KB/sec, $n = 1$, and $\lambda = 10$ times/min

Fig. 4(a) and (b), respectively. In the first stage, we obtain the capacity of Internet bandwidth and the expected total profit by using SQP method [8]. In the second stage, continuing the statement regards as the adjustment method of settlement rate. The process is iteratively performed till a Nash equilibrium point has been reached.

V. NUMERICAL RESULTS AND ANALYSIS

In this section we use numerical approach to analyze the effect of changing the settlement policy on the interdomain-bandwidth requirement, settlement rate, and domestic tariff. We assume the user demanding in these two ISPs are the same and consider only two service levels. The outing factor $\alpha_A = \alpha_B = 0.3$ and $\lambda_B = 9$.

As shown in Fig 5, the settlement rate P_A^B is greater than P_B^A when the arrival rate $\lambda_A \geq 9$ due to the domestic profit is high enough for ISP_A . Moreover, the increasing rate of P_B^A is much lower than that of P_A^B . This is because of the domestic

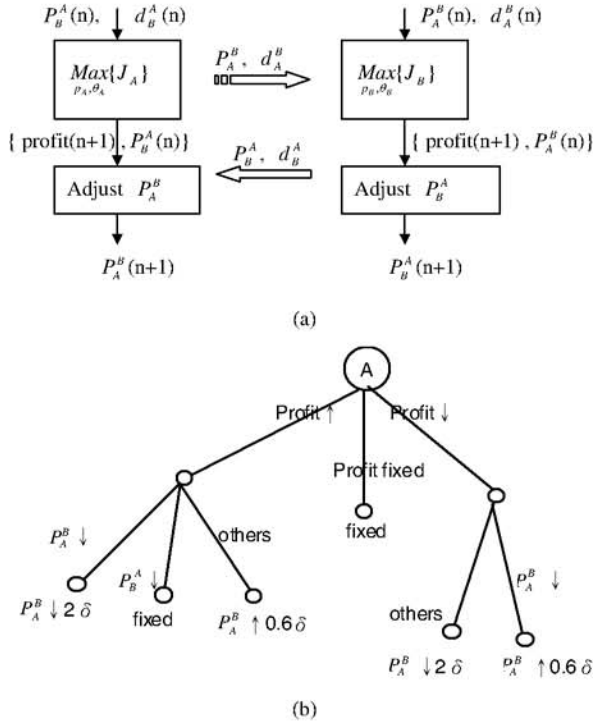


Fig. 4. The proposed (a) iterative algorithm to solve the game with incomplete information and (b) the reaction strategy to adjust P_A^B for ISP_A (δ is a stepsize)

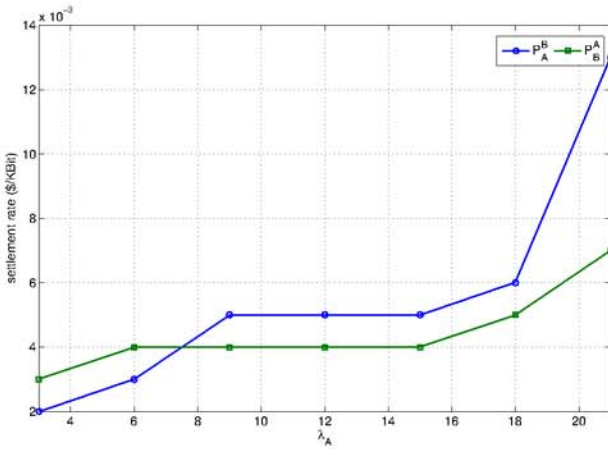


Fig. 5. Settlement rate vs. connection arrival rate

demanding of ISP_B is fixed. When the settlement rate P_A^B is increasing, the interdomain bandwidth requirement of ISP_B is decreasing as shown in Fig. 6. This is because of the ISP_B cannot recover the cost from its end-users. Finally, we discuss the relationship between the arrival rate and the domestic rate for different service levels. As shown in Fig. 7(a), the tariff for these two service levels are the same when $\lambda_A \leq 15$. This is the so-called incentive control. When the network is not congested, the ISP_A set $p_{A1} = p_{A2}$. Such price structure will attract end-user use higher service level. Similar phenomenon is shown in Fig. 7(b) as well. It should notice that the the

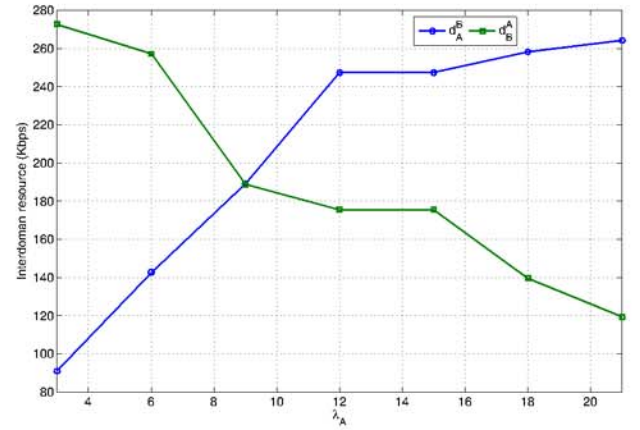
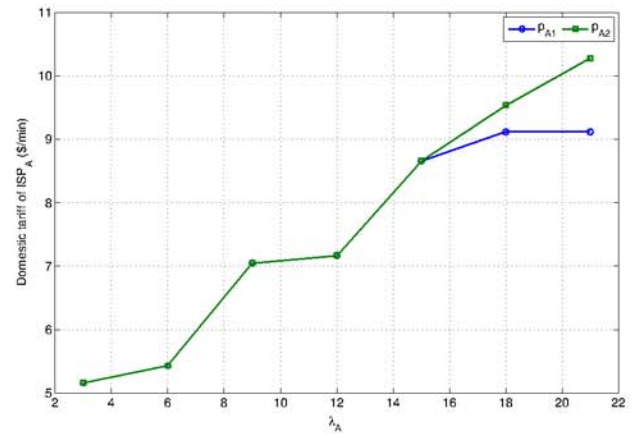
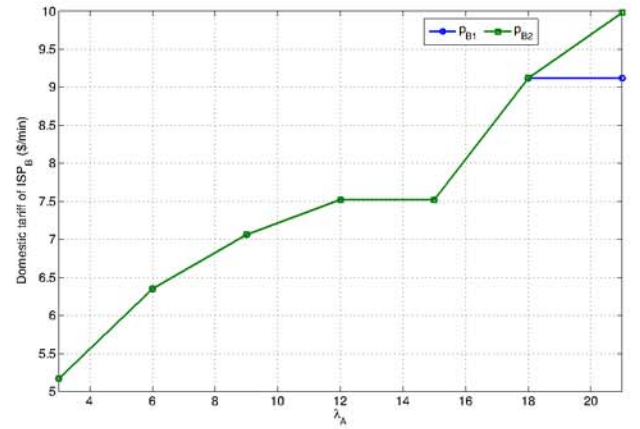


Fig. 6. Interdomain bandwidth requirement vs. connection arrival rate



(a)



(b)

Fig. 7. Domestic tariff vs. connection arrival rate

domestic tariff of ISP_A is higher than that of ISP_B when $\lambda_A \leq 13$. This is also because of that the ISP_A is much congested than ISP_B

VI. CONCLUSIONS

We have investigated the bilateral settlement problem in qualitative service and designed the corresponding market

mechanism. The settlement problem has been described as a multi-stage game with incomplete information and we found there are many Nash equilibrium points in the system. The characteristic of bilateral settlement model can be obtained by a simple numerical analysis. The numerical results have shown that a ISP will judge the marginal profit from users and the other interconnected ISP determines the bandwidth allocation. We observed the cost-shifting price structure. When the accepted settlement rate increased, the corresponding domestic tariff increased too. We also observed there exists trade off between intra-domain revenue and inter-domain revenue. If the local demand is enough and inter-domain demanding is increasing, then the settlement rate is increasing; On the other hand, if the local demand is too low and inter-domain demanding is increasing, the the settlement rate is decreasing.

REFERENCES

- [1] K. Nichols, S. Blake, F. Baker, and D. Black, "Definition of the differentiated services field (DS-field) in the IPv4 and IPv6 headers," *IETF RFC 2474*, Dec. 1998.
- [2] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss, "An Architecture for Differentiated Service," *IETF RFC 2475*, Dec. 1998.
- [3] V. Jacobson, K. Nichols, and K. Poduri, "An Expedited Forwarding PHB," *IETF RFC 2598*, June 1999.
- [4] J. Heinanen, F. Baker, W. Weiss, and J. Wroclawski, "Assured Forwarding PHB Group," *IETF RFC 2597*, Jun. 1999.
- [5] Y. Cheng and W. Zhuang, "Dynamic Inter-SLA Resource Sharing in Path-Oriented Differentiated Services Networks," *IEEE/ACM Trans. Netw.*, vol. 14, no. 3, pp. 657–670, June 2006.
- [6] P. K. Dutta, *Strategies and Games, Theory and Practice*. MIT Press, 1999.
- [7] R. J. Edell and P. P. Varaiya. (Apr.) Providing Internet Access: What we learn from the INDEX Trial. [Online]. Available: <http://www.INDEX.Berkeley.EDU/reports/99-010W>
- [8] P. Gill, W. Murray, and M. Wright, *Practical Optimization*. Academic Press, 1981.