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Mixed integer nonlinear programming (MINLP)-based bandwidth utility function on internet pricing scheme with monitoring and marginal cost

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ABSTRACT

The development of the internet in this era of globalization has increased fast. The need for internet becomes unlimited. Utility functions as one of measurements in internet usage, were usually associated with a level of satisfaction of users for the use of information services used. There are three internet pricing schemes used, that are flat fee, usage based and two-part tariff schemes by using one of the utility function which is Bandwidth Diminished with Increasing Bandwidth with monitoring cost and marginal cost. Internet pricing scheme will be solved by LINGO 13.0 in form of non-linear optimization problems to get optimal solution. The optimal solution is obtained using the either usage-based pricing scheme model or two-part tariff pricing scheme model for each services offered, if the comparison is with flat-fee pricing scheme. It is the best way for provider to offer network based on usage based scheme. The results show that by applying two part tariff scheme, the providers can maximize its revenue either for homogeneous or heterogeneous consumers.

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1. INTRODUCTION

The development of the internet in this era of globalization has increased rapidly. The need for internet usage becomes unlimited due to its easiness [1] and for internet service provider companies or ISP, it is a big challenge in satisfy their customers to meet the needs of its customers by providing the best service for consumers and still pay attention to the benefits for Internet Service Provider itself. In designing the model of internet pricing scheme, there should be a match between the price given and the satisfaction obtained by consumer. The level of satisfaction canbe related to the utility function. Utility functions were usually associated with a level of satisfaction that user gets for the use of information services used specifically relating to maximize profits in achieving specific goal [2] and can be written with $U = f\ (x_1, x_2, x_3, \dots, x_n)$ which means that $x_1, x_2, x_3, \dots, x_n$ contribute the user utility. So the well-known utility function used by researchers in pricing information services are Cobb-Douglass, Quasi-Linear, Perfect Substitute and a function of bandwidth utility functions [3]-[5]. There are three internet pricing scheme used, that is flat fee, usage based and two part tariff to be applied to Internet pricing scheme by using one of the utility function which is Cobb-Douglass modified utility function to maximize benefits to the ISP [6].

Wu and Banker [6] chose three internet pricing scheme that are flat fee, usage based and two-part tariff by applying modified utility function of Cobb Douglass in order to maximize the profits by ISP. QoS (Quality of Service) is the transmission rates, error rates and other level of measurable characteristics to support the level of progress at a service provider [7]. QoS involved a collection of data transmission-quality parameters through a communication network. Basically, QoS allows to provide better services for specific requests [8]. For instance, QoS routing is to choose single reliable and dependable paths in networks, by utilizing the packet flow from source to destination [9]. To show the efficiency of ISP in service there must be an interaction between price and QoS [10]. Besides that the QoS metric also play important role in measuring the end to end user's satisfaction [11]. Based on the research discussed by [12] the optimal internet pricing scheme for homogenous and heterogeneous consumer case (High end and Low end) is obtained in utility functions of Bandwidth with flat fee scheme by ignoring the monitoring cost and marginal cost. From the analysis done by [5], [13], it is found that utility function of Bandwidth produce maximum profit for ISP with flat fee pricing scheme for homogenous and heterogeneous (High end and Low end) consumer with monitoring cost and marginal cost. Also, based on the research conducted [14] on the models application of each traffic data it is found that the use of other utility functions can result in optimal pricing scheme

In general, the marginal costs are defined as the costs adjusted to the level of production of goods which are resulting in differences of fixed costs due to the addition of the number of units produced.While the cost of monitoring is the cost incurred by the company to monitor and control the activities carried out by the agency in managing company. In fact, the marginal cost and the monitoring cost an important in consideration for internet service provider in maximizing profits. The main contribution of this paper, then is to formulate the pricing scheme based-utility function previously discussed differentially into mixed integer nonlinear programming to enable us to seek other option in solving pricing scheme with monitoring cost and the marginal cost based on bandwidth utility function for information services as the optimization problem.

2. RESEARCH METHOD

Steps conducted in this research are as follows:

a. Conduct data processing that includes the digilib traffic and mail traffic data, which divided into two categories, based on the use during peak hours and the use non peak hours and define the parameters used.
b. Determine the information service pricing scheme models according to bandwidth utility functions with flat fee, usage-based, dan two-part tariff pricing scheme for homogeneous and heterogeneous consumers.
   1. For flat fee pricing scheme, $P_X = 0$, $P_Y = 0$ and P adalah is positive.
   2. For usage-based scheme, P_X and P_Y are positive and P = 0.
   3. For two-part tariff scheme, P, P_X and P_Y are positive.
c. Formulate bandwidth utility function according to flat fee, usage-based, and two-part tariff pricing schemes for homogeneous and heterogeneous consumers with paying attention to marginal and monitoring cots.
d. Apply the optimal pricing scheme of local data server of digilib and mail traffic data and solve the result by LINGO 13.0 then compare the pricing scheme models to each utility function for each consumers.
e. Conclude and obtain the best solution of information service pricing scheme.

3. RESULTS AND ANALYSIS

This section discusses other utility function that is also well known namely bandwidth utility function. The optimization problems are divided into two categories, which are consumer and provider problems.

a) Optimization of consumers' problem

$$\text{Max}_{X_i,Y_i,Z_i}\, U_{i_{(X_i,Y_i)}} - P_X X_i - P_Y Y_i - P Z_i \qquad (1)$$

Subject to:

$X_i \leq \bar{X}_i Z_i$

$Y_i \leq \bar{Y}_i Z_i$

$U_{i_{(X_i,Y_i)}} - P_X X_i - P_Y Y_i - P Z_i \geq 0$

$Z_i = 0$ or 1

b) Optimization of providers' problem

$$Max_{P,P_X,P_Y} \sum_i \left(P_x X_i^* + P_y Y_i^* + PZ_i^*\right) \quad (2)$$

with (X_i*,Y_i*,Z_i*) = argmax U_i (X_i,Y_i) – $P_x X_i$ – $P_y Y_i$ – PZ_i

Subject to:

$X_i \leq \bar{X}_\iota Z_i$

$Y_i \leq \bar{Y}_\iota Z_i$

$U_i(X_i, Y_i) - P_x X_i - P_y Y_i - PZ_i \geq 0$

$Z_i = 0$ or 1

c) Bandwidth utility function

According to [15] the Bandwidth utility function *:*

$$U_{kj} = U_{0j} + W_j \, ln \frac{X_{kj}}{L_{mj}} \quad (3)$$

The calculation of (3) is changed to:

$$\text{U (X,Y)} = \text{U}_0 + a \, ln \frac{X+1}{X_m+1} + b \, ln \frac{Y+1}{Y_m+1} \quad (4)$$

Table 1 and Table 2 describe the internet usage for digilib and mail data in peak and non-peak hours while Table 3 and Table 4 explain the parameter and variables used in the consumer and provider optimization problem, respectively. Table 5 and Table 6 describe to the decision variables use for consumer and provider optimization problem.

Table 1. Internet Usage Data during Peak and Non-Peak Hours for Digilib Traffic

	Digilib (byte)	*Digilib* (kbps)
$\bar{X} = \bar{X}_1$	2,278.00	2.22
$\bar{X}_2$	1,927.64	1.88
X_m	515.44	0.50
$\bar{Y} = \bar{Y}_1$	14,755.36	14.41
$\bar{Y}_2$	4,465.03	4.36
Y_m	1,151.24	1.12

Table 2. Internet Usage Data during Peak and Non-Peak Hours for Mail Traffic

	Mail (byte)	*Mail* (kbps)
$\bar{X} = \bar{X}_1$	460,959.55	450.16
$\bar{X}_2$	180,157.62	175.94
X_m	53,958.72	52.69
$\bar{Y} = \bar{Y}_1$	372,947.24	364.21
$\bar{Y}_2$	339,505.75	331.55
Y_m	141,906.85	138.58

Table 3. Parameters for Consumers' Optimization Problem

Symbol		Meaning
P	:	The costs incurred when following the services provided
P_x	:	The price provided by the service provider (ISP) during peak hours (09.00 – 16.59).
P_y	:	The price provided by the service provider (ISP) during not busy hours. (17.00 – 08.59).
$U_i(X_i, Y_i)$	:	The utility function from consumer i with X_i is the level of service usage during peak hours and Y_i is the level of service usage during not busy hours.

Table 4. Parameters for Optimization Provider Problem

Symbol		Meaning
X_i * = $X_{i_{(P_x,P_y,P)}}$	:	The level of consumer service consumption *i* during peak hours.
Y_i* = $Y_{i_{(P_x,P_y,P)}}$	:	The level of consumer service consumption *i* during not busy hours.
Z_i* = $Z_{i_{(P_x,P_y,P)}}$	:	Consumer variable *i* to show the participation of the scheme
$U_{i_{(X_i,Y_i)}}$	:	The utility function from consumer i with X_i is the level of service usage during peak hours and Y_i is the level of service usage during not busy hours.
$\bar{X}_\iota$	:	The highest level of consumers *i* in using the service during peak hours.
$\bar{Y}_\iota$	:	The highest level of consumers *i* in using the service during not busy hours.

Table 5. Decision Variable for Consumers' Optimization Problem

Symbol		Meaning
X_i	:	The level of consumption consumer *i* on the peak hours.
Y_i	:	The level of consumption consumer *i* on the non-peak hours.
Z_i	:	The decision variable which have value 1 if consumers chosen to join the program and have value 0 if consumers didn't join the program.
$\overline{X_i}$	:	The maximum level of consumption consumer *i* on the peak hours.
$\overline{Y_i}$	:	The maximum level of consumption consumer *i* on the non-peak hours.

Table 6. Decision Variable for Provider Optimization Problem

Symbol		Meaning
P	:	The cost required to join the service program.
P_x	:	The price of the service specified by ISP during peak hours.
P_y	:	The price of the service specified by ISP during non-peak hours.

d) Digilib traffic data

In this section the explanations about provider optimization with three pricing scheme which applied to digilib traffic data for homogeneous consumers and heterogeneous consumers are described. The parameters value usage for will to show in the Tables 7-9.

Table 7. Parameter Values for Homogeneous Consumers for Digilib Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
A	5	5	5
B	4	4	4
$\overline{X}$	2.22	2.22	2.22
X_m	0.50	0.50	0.50
$\overline{Y}$	14.41	14.41	14.41
Y_m	1.12	1.12	1.12

By substituting the parameters value in Table 7, it can be model on the homogeneous consumer based on (4) equation as shown by the (5):

$$Max\ Px\ X + Py\ Y + PZ + (X+Y)C - U_0 + 5\ ln\frac{X+1}{X_m+1} + 4\ ln\frac{Y+1}{Y_m+1} \quad (5)$$

Subject to:

$$X \leq 2.22\ Z \quad (6)$$

$$Y \leq 14.41\ Z \quad (7)$$

$$Z = 1 \quad (8)$$

Table 8. Parameter Values for High End and Low End Heterogeneous Consumers for Digilib Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
a_1	5	5	5
a_2	4	4	4
b_1	3	3	3
b_2	2	2	2
$\overline{X}_1$	2.22	2.22	2.22
$\overline{X}_2$	1.88	1.88	1.88
X_m	0.50	0.50	0.50
$\overline{Y}_1$	14.41	14.41	14.41
$\overline{Y}_2$	4.36	4.36	4.36
Y_m	1.12	1.12	1.12

Model for High end and Low end Heterogeneous consumers shown at (9).

$$Max\ PxX_1 + PyY_1 + PxX_2 + PyY_2 + PZ + (X_1 + Y_1)C + (X_2 + Y_2)C - (\ (U_0\ + 5\ ln\ \frac{X+1}{X_m+1} + 3\ ln\ \frac{Y+1}{Y_m+1}) + (U_0\ + 4\ ln\ \frac{X+1}{X_m+1} + 2\ ln\ \frac{Y+1}{Y_m+1})) \quad (9)$$

Subject to:

$$X_1 \leq 2.22\ Z \quad (10)$$

$$Y_1 \leq 14.41\ Z \quad (11)$$

$$X_2 \leq 1.88\ Z \quad (12)$$

$$Y_2 \leq 4.36Z \quad (13)$$

$$Z = 1 \quad (14)$$

Based on the Table 9 it can be model shown (15) as following.

$$Max\ PxX_1 + PyY_1 + PxX_2 + PyY_2 + PZ + (X_1 + Y_1)C + (X_2 + Y_2)C - (\ (U_0\ + 5\ ln\ \frac{X+1}{X_m+1} + 4\ ln\ \frac{Y+1}{Y_m+1}) + (U_0\ + 5\ ln\ \frac{X+1}{X_m+1} + 4\ ln\ \frac{Y+1}{Y_m+1})) \quad (15)$$

Subject to :

$$X \leq 2.22\ Z \quad (16)$$

$$Y \leq 14.41\ Z \quad (17)$$

$$X_2 \leq 1.88\ Z \quad (18)$$

$$Y_2 \leq 4.36\ Z \quad (19)$$

$$Z = 1 \quad (20)$$

Table 9. Parameter Values for High Demand and Low Demand Heterogeneous Consumers of Digilib Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
a_1	5	5	5
a_2	5	5	5
b_1	4	4	4
b_2	4	4	4
$\overline{X}_1$	2.22	2.22	2.22
$\overline{X}_2$	1.88	1.88	1.88
X_m	0.50	0.50	0.50
$\overline{Y}_1$	14.41	14.41	14.41
$\overline{Y}_2$	4.36	4.36	4.36
$\boldsymbol{Y_m}$	1.12	1.12	1.12

e) Mail traffic data

In this section we will to explain about optimization of provider with three pricing scheme which applied to Mail traffic data for homogeneous consumers and heterogeneous consumers. The parameter value usage is shown in Table 10 Table 11 and Table 12.

Table 10. Parameter Values for Homogeneous Consumers for Mail Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
A	5	5	5
B	4	4	4
$\overline{X}$	450.16	450.16	450.16
$\boldsymbol{X_m}$	52.69	52.69	52.69
$\overline{Y}$	364.21	364.21	364.21
$\boldsymbol{Y_m}$	138.58	138.58	138.58

By substituting the parameters value in Table 10, it can be modelled on the homogeneous consumer based on the equation of Cobb-Douglas utility function as shown by the (21):

$$Max\ Px\,X + Py\,Y + PZ + (X+Y)C - U_0 + 5\ ln\frac{X+1}{X_m+1} + 4\ ln\frac{Y+1}{Y_m+1} \quad (21)$$

Subject to:

$$X \leq 450.16\,Z \quad (22)$$

$$Y \leq 364.21\,Z \quad (23)$$

$$Z = 1 \quad (24)$$

Table 11. Parameter Values for High End and Low End Heterogeneous Consumers of Mail Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
a_1	5	5	5
a_2	4	4	4
b_1	3	3	3
b_2	2	2	2
$\overline{X}_1$	450.16	450.16	450.16
$\overline{X}_2$	175.94	175.94	175.94
X_m	52.69	52.69	52.69
$\overline{Y}_1$	364.21	364.21	364.21
$\overline{Y}_2$	331.55	331.55	331.55
Y_m	138.58	138.58	138.58

Model for High end and Low end Heterogeneous consumers by using Table 11, is shown in (25).

$$Max\ PxX_1 + PyY_1 + PxX_2 + PyY_2 + PZ + (X_1+Y_1)C + (X_2+Y_2)C - \left(\left(U_0 + 5\ ln\frac{X+1}{X_m+1} + 3\ ln\frac{Y+1}{Y_m+1}\right) + \left(U_0 + 4\ ln\frac{X+1}{X_m+1} + 2\ ln\frac{Y+1}{Y_m+1}\right)\right) \quad (25)$$

Subject to:

$$X_1 \leq 450.16\,Z \quad (26)$$

$$Y_1 \leq 364.21\,Z \quad (27)$$

$$X_2 \leq 175.94\,Z \quad (28)$$

$$Y_2 \leq 331.55\,Z \quad (29)$$

$$Z = 1 \quad (30)$$

Based on the Table 12, it can be modelled like stated in (32).

$$Max\ PxX_1 + PyY_1 + PxX_2 + PyY_2 + PZ + (X_1+Y_1)C + (X_2+Y_2)C - \left(\left(U_0 + 5\ ln\frac{X+1}{X_m+1} + 4\ ln\frac{Y+1}{Y_m+1}\right) + \left(U_0 + 5\ ln\frac{X+1}{X_m+1} + 4\ ln\frac{Y+1}{Y_m+1}\right)\right) \quad (32)$$

Subject to:

$$X_1 \leq 450.16\,Z \quad (33)$$

$$Y_1 \leq 364.21\,Z \quad (34)$$

$$X_2 \leq 175.94\,Z \quad (35)$$

$$Y_2 \leq 331.55Z \quad (36)$$

$$Z = 1 \quad (37)$$

Table 13 to Table 18 explain solutions by using LINGO 13.0 for digilib traffic data and mail traffic data. As Table 19 explain the recapitulation of result conducting by using LINGO 13.0, it can be seen that for highest revenue obtained by the provider if they offer two part tariff pricing scheme, for high end and low end user for each traffic data in network. The two-part tariff system can be considered a best option for provider to be promoted due to the subscription fee and usage based scheme that allow provider to maintain its network.

Table 12. Parameter Values for High Demand and Low Demand Heterogeneous Consumers for Mail Traffic

Parameters	Flat Fee	Usage Based	Two Part Tariff
a_1	5	5	5
a_2	5	5	5
b_1	4	4	4
b_2	4	4	4
$\overline{X}_1$	450.16	450.16	450.16
$\overline{X}_2$	175.94	175.94	175.94
X_m	52.69	52.69	52.69
$\overline{Y}_1$	364.21	364.21	364.21
$\overline{Y}_2$	331.55	331.55	331.55
Y_m	138.58	138.58	138.58

Table 13. The Solution for Digilib Traffic for Homogeneous Consumer By LINGO 13.0

Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	159.51	482.11	514.31
Iterations	30	32	24
GMU(K)	21	22	21

Table 14. The Solution for Traffic for High End and Low End Heterogeneous Consumer by LINGO 13.0

Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	217.1	580.66	590.66
Iterations	35	38	38
GMU(K)	23	24	24

Table 15. The Solution for Digilib Traffic for High Demand and Low Demand Heterogeneous Consumer by LINGO 13.0

Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	209.91	573.51	583.51
Iterations	35	20	20
GMU(K)	23	24	24

Table 16. The Solution for Mail Traffic for Homogeneous Consumer by LINGO 13.0

	Pricing Scheme		
Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	8,099.54	24,376.9	28,888.5
Iterations	13	15	15
GMU(K)	21	22	21

Table 17. The Solution for Mail Traffic for High End and Low End Heteregeneous Consumer by LINGO 13.0

	Pricing Scheme		
Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	13,148	35,686.4	35,696.4
Iterations	15	18	38
GMU(K)	23	24	24

Table 18. The Solve Mail Traffic for High Demand and Low Demand Heterogeneous Consumer by LINGO 13.0

	Pricing Scheme		
Solver Status	Flat Fee	Usage Based	Two part tariff
Model class	NLP	NLP	NLP
State	Local optimal	Local optimal	Local optimal
Objective	13,125.3	35,663.7	35,673.7
Iterations	15	18	18
GMU(K)	23	24	24

Table 19. Recapitulation of Digilib Traffic Data

Data	Type of Pricing	Consumers		Income
Digilib	flat-fee	Homogeneous	159.5130	1,155.939
		Heterogeneous High end & Low end	482.1130	
		Heterogeneous High demand & Low demand	514.3130	
	Usage based	Homogeneous	217.0590	1,388.377
		Heterogeneous High end & Low end	580.6590	
		Heterogeneous High demand & Low demand	590.6590	
	Two-part Tariff	Homogeneous	209.9082	1,366.9246
		Heterogeneous High end & Low end	573.5082	
		Heterogeneous High demand & Low demand	583.5082	

4. CONCLUSION

Based on the optimization result of the internet pricing scheme by considering marginal and monitoring cost of *Bandwidth* utility function, the optimal solution is obtained using the either *usage-based* pricing scheme model or *two-part tariff* pricing scheme model for each services offered, if we compared with *flat-fee* pricing scheme. It is the best way for provider to offer network on usage based pricing scheme.

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Yunita received her S.Si degree in Mathematics from Sriwijaya University, South Sumatera, Indonesia in 2006. Then she received her M.Cs in Mathematics from Gadjah Mata University, Yogyakarta in 2012. She has been an Informatics Engineering Department member at Faculty of Computer Science, Sriwijaya University South Sumatera Indonesia since 2015. Her research interests include artificial intelligence and its application.

Shintya Apriliyani is currently is an undergraduate student at Mathematics Department, Faculty of Mathematics and Natural Sciences, Sriwijaya University. She is currently on final stage of her thesis submission. Her topic interest includes Optimization and its application on pricing of information service with marginal and monitoring cost.